STATE OF OHIO
Frank J. Lausche, Governor
DEPARTMENT OF NATURAL RESOURCES
A. W. Marion, Director
DIVISION OF GEOLOGICAL SURVEY
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REPORT OF INVESTIGATIONS NO. 9
(Contribution No. 1, Lake Erie Geological Research Program)

1950 INVESTIGATION OF LAKE ERIE SEDIMENTS, VICINITY OF SANDUSKY, OHIO

By
HOWARD J. PINCUS
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INTRODUCTION

The Lake Erie Geological Research Program has been established to investigate geological processes at work in and around Lake Erie, and to develop a picture of the general geology of the lake.

A specific immediate objective is to comprehend more fully the processes of erosion acting on the shores of the lake. This requires the investigation of modes of sediment transportation, sources of and paths along which shore materials are moved, effects of wave action and of wind on waves breaking in confined areas, changes with time of shore and adjacent offshore topography, vertical and horizontal aspects of lake currents, and the effects of works of construction on shoreline processes.

This report is concerned with sediments collected in the mouth of Sandusky Bay and along the Cedar Point and East Harbor beaches. Other phases of the continuing investigation are to be covered in later reports.

The authors feel that much more work must be done before sedimentary processes in this area can be adequately described, therefore very little interpretation of results is included in the text. Most of the data are presented in graphic form.

Field work was carried out from early September through November, 1950, under the supervision of the senior author. Laboratory analyses were performed by the two junior authors during the winter of 1950-1951 at the Ohio State University. The text of the report has been prepared by the senior author.

ACKNOWLEDGMENTS

The active cooperation of a number of individuals and agencies have made possible the program's rapid growth. Special mention is due Mr. F. O. Kugel, Chief of Ohio's Division of Shore Erosion, Mr. John H. Melvin, Chief of the Ohio Division of Geological Survey, Dr. N. Paul Hudson, Dean of the Graduate School of the Ohio State University, and Dr. Edmund Spieker, Chairman of the Geology Department of the Ohio State University.

Mr. Gene Garrison of the Ohio Geological Survey and Mr. Earl Sanderson and Mr. Charles Hahn, both of the Ohio Division of Water, participated in the collection of some of the samples. Dr. Rudolph Speiser of the Department of Metallurgy, the Ohio State University, enthusiastically assisted the senior author in collecting a number of samples from the lake bottom.

These are but a few of the names of those to whom the personnel of the Lake Erie Geological Research Program are deeply grateful.

GENERAL GEOLOGY: A BRIEF OUTLINE

The youthfully dissected plain in and around Sandusky slopes gently toward the north, the surface streams flowing into the lake. The land area is part of the Eastern lake section of the Central Lowland Province which is, in turn, part of the Interior Plains (Fenneman, 1928). The lake area studied covers the line between the small, shallow Western section and the broad, even-bottomed and somewhat deeper Central section (Carman, 1946).

Sandusky Bay is a drowned river valley, the shoreline displaying the characteristic features resulting from submergence.

The plain is underlain by nearly horizontal Silurian and Devonian rocks covered with glacial deposits and post-glacial lake clays. The accompanying map (Fig. 1) and section summarize the bedrock geology. Structurally, the bedrock is on the east flank of the Cincinnati Arch.

Both the Illinoian and Wisconsin ice sheets glaciated the area. In the vicinity of Sandusky Bay, a thin mantle of glacial till, approximately 5 feet thick, lies upon bedrock; the till is overlain by about 20 feet of glacial clay (Shaffer, 1951). Locally bedrock crops out, especially where vigorous wave action has removed the overlying unconsolidated materials.

Lake clays occur at the surface almost everywhere in the vicinity of Sandusky. The widespread occurrence of these very easily eroded materials accounts in part for the rapid rate of shoreline retreat in Sandusky Bay (Shaffer, 1951).

Although good beaches are usually rather rare along the south shore, there are conspicuous sand beaches at Cedar Point, Bay (Sand) Point, and East Harbor (Fig. 2a, 1). Some of the beach material is believed to have been derived, in part, from the erosion of till occurring both along the shore and offshore, and, in part, from the dolomitic and calcitic bedrock (White, 1943).

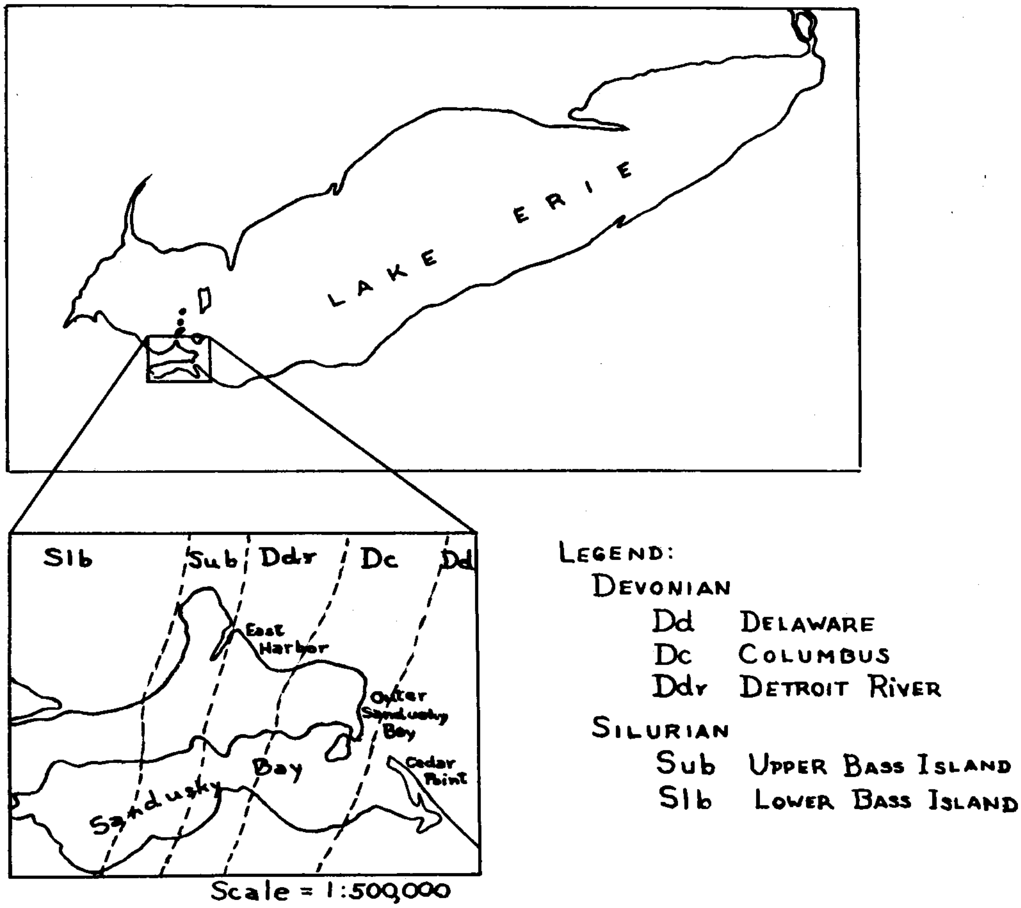
Marsh deposits occur just southeast of the Cedar Point spit and the East Harbor beach, and along the shoreline of inner Sandusky Bay.

Marl deposits, which have been exploited commercially, occur in large quantities in the swampy area south of the bay.

GEOLOGIC SECTION

System	Series or Formation			Thickness in Feet	Rock Character	Location	Source of Information
DEVONIAN			Delaware	30- 70	Limestone, dark to bluish gray, hard, with some flint and shale	Underlying Sandusky	Generalized Section of Ohio from Bulletin 44, 4th series, Geol. Survey of Ohio
DEVONIAN			Columbus	80-100	Limestone, light-colored, locally changing to dolomite	Rock of shore of Marblehead east of Coast Guard station	White, George—— Geology of the Lake Erie Shore in Ohio From The Michigan Boundary to Marblehead
DEVONIAN	Detroit River Group		Lucas	100-200	Dolomite, gray to drab, thin to massive-bedded	Exposed from east edge of Lakeside to Coast Guard station	
DEVONIAN	Detroit River Group		Amherstburg	60- 80	Dolomite, brown, massive-bedded	Well exposed through Lakeside	
SILURIAN	Bass Island Group	Upper	Raisin River	40- 60	Dolomite, drab, thin-bedded	Known on islands only	
SILURIAN	Bass Island Group	Upper	Put-in-Bay	40- 60	Dolomite, drab, medium-bedded, brecciated, rough textured	Prominently exposed on Catawba Island	
SILURIAN	Bass Island Group	Lower	Tymochtee	125-175	Dolomite, thin-bedded to shaly, with calcareous shale partings	Exposed at lake level west side of Catawba Island	
SILURIAN	Bass Island Group	Lower	Greenfield	75-125	Dolomite, light, medium-bedded	West of Camp Perry, not exposed at shore	

Figure 1



Index Map and Generalized Geologic Map of Sandusky Bay Area.
(Geology based on Carman, 1946)

FIELD METHODS

Samples of sediment from the floor of Sandusky Bay were collected from a 26-foot diesel-powered converted Army towboat equipped with a pipe tripod astern for lowering and raising the heavier types of sampling equipment.

Most of the sampling equipment, on loan from Ohio's Division of Water, consisted of types of gear similar to those in general use in shallow water surveys.

(a) Check-valve sampler (Fig. 3a)

Samples of the uppermost 6" to 1' of the lake bottom sediment were collected with a check-valve sampler coupled to 1" pipe of sufficient length to allow collection of samples in water up to 20' deep; using a single stroke, the rig is thrust downward by hand. The sampler consists of a 1" copper tube 1' long (wall thickness .046"), topped by a gravity type check-valve which is, in turn, coupled to the 1" handling pipe. The sample is extruded with a tightly fitting piston which is forced through the sample tube.

(b) Jetting sampler (Fig. 3b)

For obtaining samples below the uppermost layer, the sediment was penetrated with a jetting rig consisting of 2" pipe through which a stream of water flows under pressure supplied by a small, powered pump. Samples are collected by cutting off the pressurized stream when the desired penetration has been made; the sample is brought to the surface by passing a check-valve sampler through the 2" pipe to the sediment below. Penetrations of over 20' were obtained by this method.

The uppermost part of poorly compacted sediment is somewhat resorted by the washing which accompanies the jetting process.

In several cases, sediment was collected by washing it up through an inner pipe; the results obtained from these samples are of little value because of the considerable resorting which must have taken place (# 4-3, 4-4, 4-5, 5-4, 6-2, 6-3).

(c) Pile-driver piston sampler (Fig. 3c)

Core samples of the uppermost 2' to 3' of lake bottom sediment were collected with a pile-driver type of piston sampler. A $1\frac{3}{4}$" copper tube 3' long is hammered into the sediment by a weight which slides on a narrow width pipe coupled to the coring tube. Inside the coring tube, a piston eliminates the downward thrust of the overlying column of water as the coring tube is withdrawn; during the downward penetration by the tube, the piston rests on the top of the layer of sediment while the tube slides downward past it. The series of jolts imposed on the sediment by the hammering process distorts the stratification of the sample, but the larger differences in layering are still detectable.

(d) Beach drive sampler (Fig. 3d)

Samples of beach materials were collected by driving on a 2" steel pipe, $1\frac{1}{2}$' long into the beach material. The pipe has a sharpened bevel on the lower end, air escape ports near the upper end, and a driving cap on the upper end. A sledge hammer is used to drive the pipe about 1' into the sediment; very frequently complete samples may be removed from the tube by tapping the side of the tube. When tapping is not successful, the sample must be extruded if stratification is to be observed.

The mapping of locations at which samples were collected was carried out as follows:

Positions of underwater samples were determined by turning horizontal angles on at least three shore points for each sample locality, using a sextant in the horizontal plane as the sighting instrument; positions were plotted with a three-arm protractor. Depth of water at each locality was measured with a lead line. Most positions of beach samples were mapped with Brunton; at several localities air photographs were used in combination with Brunton. Some shore positions were determined by sextant, using the technique outlined above.

LABORATORY METHODS

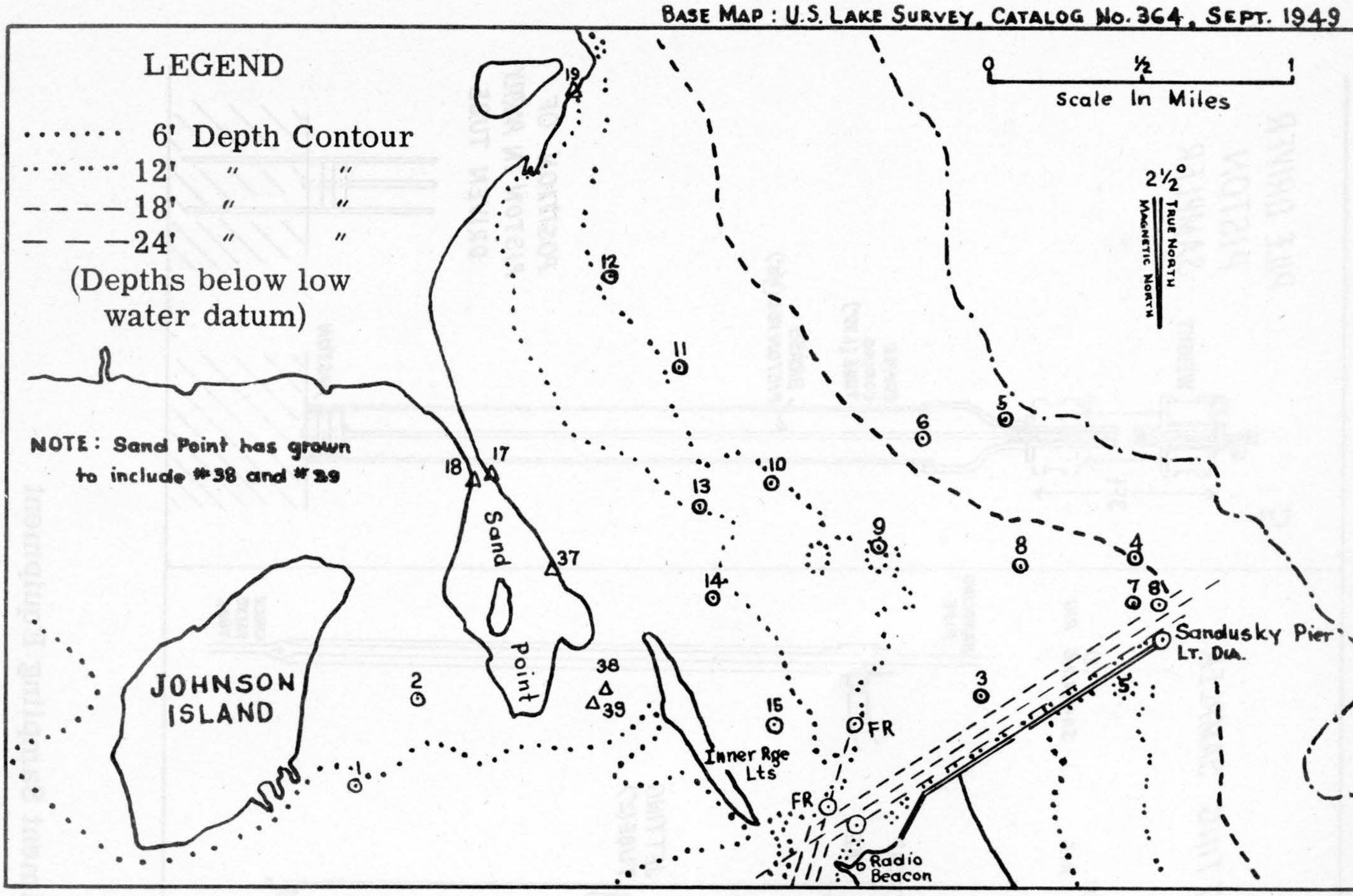
The samples have been analyzed for distribution of grain sizes and for mineral content.

Grain sizes were determined principally by sieve analysis, using Wentworth's grade scale (Table 1); the notation used is that of the phi (ϕ) scale. Fractions consisting of grains smaller than 1/16 mm. ($+4\phi$) were analyzed by the method of elutriation by pipette (Krumbein and Pettijohn, 1938).

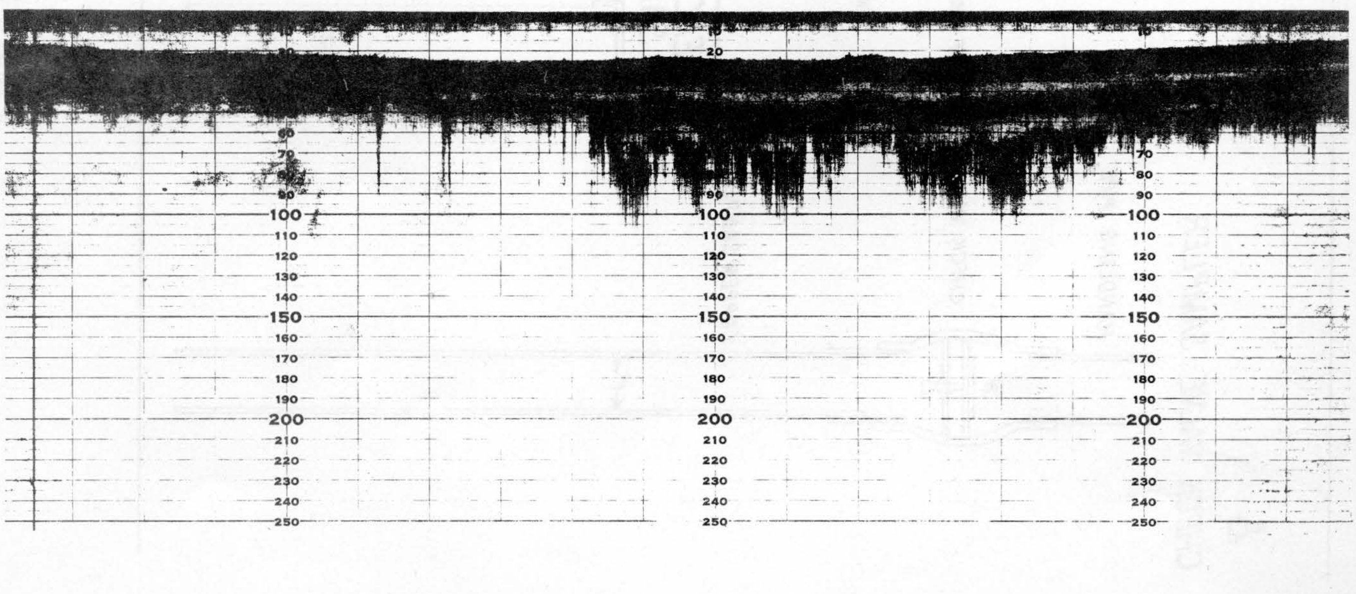
The proportion of carbonate in the sediment was measured by determining the carbonate (weight) loss through digestion by acid (HCl).

Figure 2

Bottom Topography of Outer Sandusky Bay



(a) Contours Based on U. S. Lake Survey Chart No. 364



(b) Fathogram (Echo-sounding Record) across the mouth of Sandusky Bay. (Contributed by Kelley Island Lime and Transport Company)

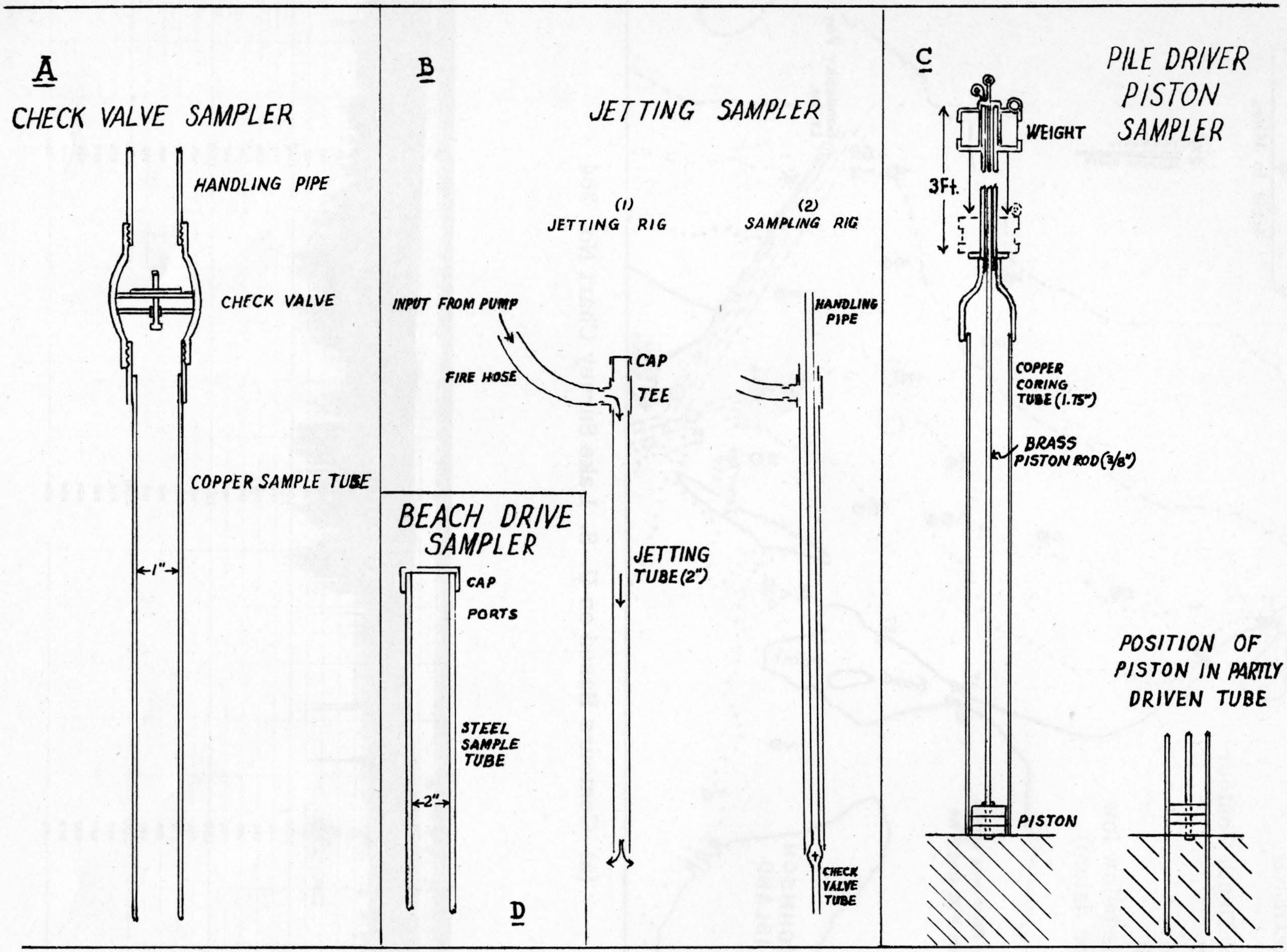


Figure 3 Sediment Sampling Equipment

Mineralogical determinations were made with the polarizing microscope; index of refraction was the principal identifying optical property. Heavy minerals were separated from quartz-rich sediments by selective settling in high density liquid (bromoform). Abundance of total heavy minerals has been determined in terms of proportion of the total sample; abundance of individual heavy minerals has been determined in terms of proportion of total heavy minerals. Proportions of heavy minerals within any one grade have not yet been evaluated (Rubey, 1933).

Grain shape, degree of rounding, and grain surface characteristics were studied with the binocular microscope, but data describing these features have not yet been assembled in any systematic way.

SUMMARY OF ANALYTICAL RESULTS

Outer Sandusky Bay

The bottom topography of outer Sandusky Bay and the positions of sample localities are shown in Fig. 2.

Mechanical Analyses

The mechanical analyses have been expressed in phi (ϕ) units (Table 1); ϕ units are conveniently manipulated and are easily transformed to geometric and logarithmic measures. In order to avoid confusion in the discussions which follow, it should be recalled that increasing values for ϕ correspond to decreasing values for grain size.

The following statistics have been calculated for the frequency distributions of grain size:

Phi Median (Md_ϕ): That ϕ value which divides the sample into two equal parts <u>by weight</u>. Md_ϕ is easily determined by reading the ϕ value which corresponds to the 50% value on the ordinate of the frequency distribution curve. This statistic is used as an average value of grain size.

Phi Quartile Deviation (QD_ϕ): A measure of spread of the frequency (weight) distribution of grain sizes in a sample, given as ½ the number of ϕ units (or Wentworth grades) between the first and third quartiles. Or,

$$QD_\phi = (Q_{3\phi} - Q_{1\phi})/2$$

The quartiles are ϕ values corresponding to the 25% and 75% values on the cumulative curve. A measure of spread, as applied to grain size distributions, is also a measure of sorting. QD_ϕ may be converted to Trask's sorting coefficient S_ϕ by the simple relation

$$QD_\phi = \log_2 S_\phi ,$$

or by referring to a conversion chart (Krumbein and Pettijohn, 1938, Fig. 110, p. 235).

Name		Grade Size (mm.)	Phi (ϕ) Units*
Boulder		Above 256	< -8
		256	-8
Cobble		128	-7
		64	-6
		32	-5
		16	-4
Pebble		8	-3
		4	-2
Granule		2	-1
	Very coarse	1	0
	Coarse	1/2	+1
Sand	Medium	1/4	+2
	Fine	1/8	+3
	Very fine	1/16	+4
		1/32	+5
Silt		1/64	+6
		1/128	+7
		1/256	+8
Clay		Below 1/256	>+8

* $\phi = -\log_2 W$, where W = diameter in mm.

TABLE 1

Wentworth's Size Classification and The Phi Scale

Phi Quartile Skewness (Skq_ϕ): A measure of the asymmetry of the frequency distribution curve, measured in terms of the departure of the phi median (Md_ϕ) from the midpoint of the two phi quartiles, $Q1_\phi + Q3_\phi$. Or,

$$Skq_\phi = (Q_{1\phi} + Q_{3\phi})/2 - Md_\phi .$$

Skq_ϕ may then be converted to Trask's measure of skewness, Sk, using the chart or equations on pp. 237 and 238 in Krumbein and Pettijohn, 1938. This transformation is, however, only an optional operation.

Phi Quartile Kurtosis (Kq_ϕ): A measure of the peakedness of the frequency distribution curve, evaluated as follows:

$$Kq_\phi = (Q_{3\phi} - Q_{1\phi})/2\,(P_{90\phi} - P_{10\phi}),$$

where $P_{10\phi}$ and $P_{90\phi}$ are the ϕ values corresponding to the 10% and 90% values on the ordinate of the cumulative frequency distribution curve. Values of Kq_ϕ decrease with increasing peakedness of the frequency distribution curve.

The values of phi medians (Md_ϕ) and phi quartile deviations (QD_ϕ) for surface samples at the respective localities have been plotted on a map of the area, and contours have been drawn on these values (Fig. 4 and 5). It must be recognized that the contours presented are at best very rough approximations; much more complete coverage of the bay area is required before detailed interpretations can be made with confidence.

The contours drawn on these two sets of data are roughly parallel in the northwestern part of the bay; in the southeastern sector they intersect in fairly large angles. There does not appear to be a simple relation between Md_ϕ and QD_ϕ which holds for the entire outer bay area.

Values of Trask's sorting factor (So), phi quartile skewness (Skq_ϕ), Trask's skewness (Sk), and phi quartile kurtosis (Kq_ϕ) appear in Table 2.

Taking values of So below 2.5 as indicative of well-sorted sediments (Krumbein and Pettijohn, 1938, p. 232), all but two of the samples fell within this category.

There appears to be no simple areal pattern for any of the measures of skewness or kurtosis.

Mineralogical Analyses

The percent by weight of heavy minerals occurring at each locality is plotted and contoured on Fig. 6. Again, these contours are drawn on only very scanty data; the values for each locality have been entered on the map so that the reader who chooses to ignore the contours may study the values on which the contours are based.

The proportion of the heavy minerals made up of specific, easily identified minerals are shown in Fig. 7-11. Values which are odd integral multiples of 2.5 are not to be taken as accurate to 0.5%; they are merely midpoints of intervals with a spread of 5%.

Sandusky Bay Locality No.	Sample No.	Trask's Sorting Factor (So)	ø Quartile Skewness (Skqø)	Trask's Skewness (Sk)	Log_{10} (Sk)	ø Quartile Kurtosis (Kqø)
1	1-1	2.51	+.05	.93	-.03	
2	2-1A	1.10	-.05	1.07	+.03	
3	3-3E	7.40	-.60	2.29	+.36	
4	4-2	1.15	0	1.00	0	
5	5-1D	1.50	+.10	.88	-.06	
6	6-1A	1.35	-.05	1.07	+.03	
7	7	1.10	-.05	1.07	+.03	
8	8	1.35	+.05	.93	-.03	
9	9	1.50	0	1.00	0	.24
10	10	1.30	-.10	1.15	+.06	.24
11	11	1.20	+.05	.93	-.03	.19
12	12	1.27	+.05	.93	-.03	.25
13	13	1.20	+.05	.93	-.03	.28
14	14	1.10	-.05	1.07	+.03	.12
17	17	1.45	+.05	.93	-.03	.31
37	37	1.25	+.10	.88	-.06	.25
38	38	1.20	-.05	1.07	+.03	.21
39	39	1.20	-.05	1.07	+.03	.25

TABLE 2
Sorting and Skewness, Sandusky Bay Bottom Surface Samples

From these diagrams, the following relations are apparent:

(a) Magnetite-ilmenite (Fig. 7) and amphibole (principally hornblende) (Fig. 8) show a striking reciprocal relationship.

(b) The pattern of garnet (Fig. 9) is similar to that of magnetite-ilmenite (Fig. 7), except for the central part of the contoured area.

(c) The areal distributions of hypersthene (Fig. 11) and zircon (Fig. 10) do not show a clear-cut relation either to the above mentioned mineral distributions or to each other.

(d) In the northwestern part of the bay, the total heavy mineral pattern (Fig. 6) is similar to that of QDϕ.

Relations between mineral content and phi median (Mdϕ) in surface samples are shown in Fig. 13 and 14. The lines drawn between symbols representing individual minerals are linkage lines which tie the data together along a specific track, or traverse; these lines are not to be interpreted as curves of mineral content vs. Mdϕ. In Fig. 13, the traverses are roughly parallel to bottom (topographic) contours; the traverses of Fig. 14 are roughly normal to those of Fig. 13.

In Fig. 13, the only clear trends are the decrease in amphibole and the increase in magnetite-ilmenite as Mdϕ increases (or median grain size decreases). In Fig. 14, the same trends exist within the range of values of Mdϕ in Fig. 13 (2.2-3.3), but the trends are less clear; for values of Mdϕ greater than 3.3, these trends show a marked reversal of slope. Additional samples are being collected in this area to provide a more adequate description of the relations involved.

With regard to the patterns of the linkage lines in Fig. 13 and 14, the following relations are observed:

(a) The reciprocal relation between amphibole and magnetite-ilmenite is quite consistent.

(b) The garnet pattern is usually somewhat similar to that of the magnetite-ilmenite.

(c) The hypersthene and zircon patterns do not appear to resemble any other patterns, except for the 37-13-10-6-5 hypersthene pattern (Fig. 14), which resembles the garnet pattern for the same traverse.

The relations just mentioned are, of course, very similar to those deduced from Fig. 7-11; the same data have merely been presented in two different ways.

The carbonate content in the surface bay samples is shown in Fig. 12, the contour pattern of which is strikingly similar to that for Mdϕ (Fig. 4). The same data have been plotted in Fig. 15, with data from other areas. It is quite clear from these diagrams that the Sandusky Bay surface sediments show a progressive increase in carbonate content with decreasing grain size (increasing Mdϕ).

Subsurface Sediments

The jetting apparatus described earlier enabled determination of minimum sediment thicknesses at a number of localities; in the outer part of the bay (#4, 5, 6), minimum thicknesses of 15-20 feet were established. At #3, sand-size particles make up a layer 8 feet thick, the grains becoming much finer downward.

Mechanical analyses of vertical series of samples yield no systematic pattern. QD_ϕ and Md_ϕ appear in Fig. 16; for any one locality, neither statistic shows continuous variation with depth (vertical sequences are listed in Fig. 17, 18, 19). The data in Fig. 16 appear to fall in two diagonal bands which are roughly parallel, but the number of points in the cluster in the lower right half of the diagram is so much larger than the number of points which define the bands that it is difficult to accept the hypothesis that the bands define the relation, if any, between QD_ϕ and Md_ϕ.

Relations between mineral content and phi median (Md_ϕ) in vertical series are shown in Fig. 17, 18, 19. The design of these diagrams is the same as that of Fig. 13 and 14, the only difference being that here the linkage lines connect vertical series of samples. Again, the reciprocal relationship between amphibole and magnetite-ilmenite is apparent, but the linkage pattern for garnet is, in some series (#1, 5) somewhat similar to those for magnetite-ilmenite, and in other series (#3, 6) very similar to those for amphibole. At locality #4 (Fig. 17) and #3 (Fig. 19), the zircon and amphibole patterns are reciprocal. At locality #4 (Fig. 17) the hypersthene pattern is almost identical with the zircon pattern and is, therefore, also reciprocal to the amphibole linkage; at locality #3 (Fig. 19), the hypersthene pattern is similar to the garnet pattern.

The relations, if any, between the relative abundance of any one of these heavy minerals and phi median (Md_ϕ) are not clear. There are two few data here on which to base statements describing the degree of covariation.

With regard to carbonate content in the subsurface sample, a comparison of Fig. 15 (surface) and Fig. 20 (subsurface) shows a striking difference between surface and subsurface samples in the relation between carbonate content and phi median (Md_ϕ); variations in phi median (Md_ϕ) of the subsurface group are not accompanied by corresponding changes in carbonate content. Although both sets of samples have roughly the same range of values for carbonate, the carbonate content in the subsurface samples appears to be noticeable higher.

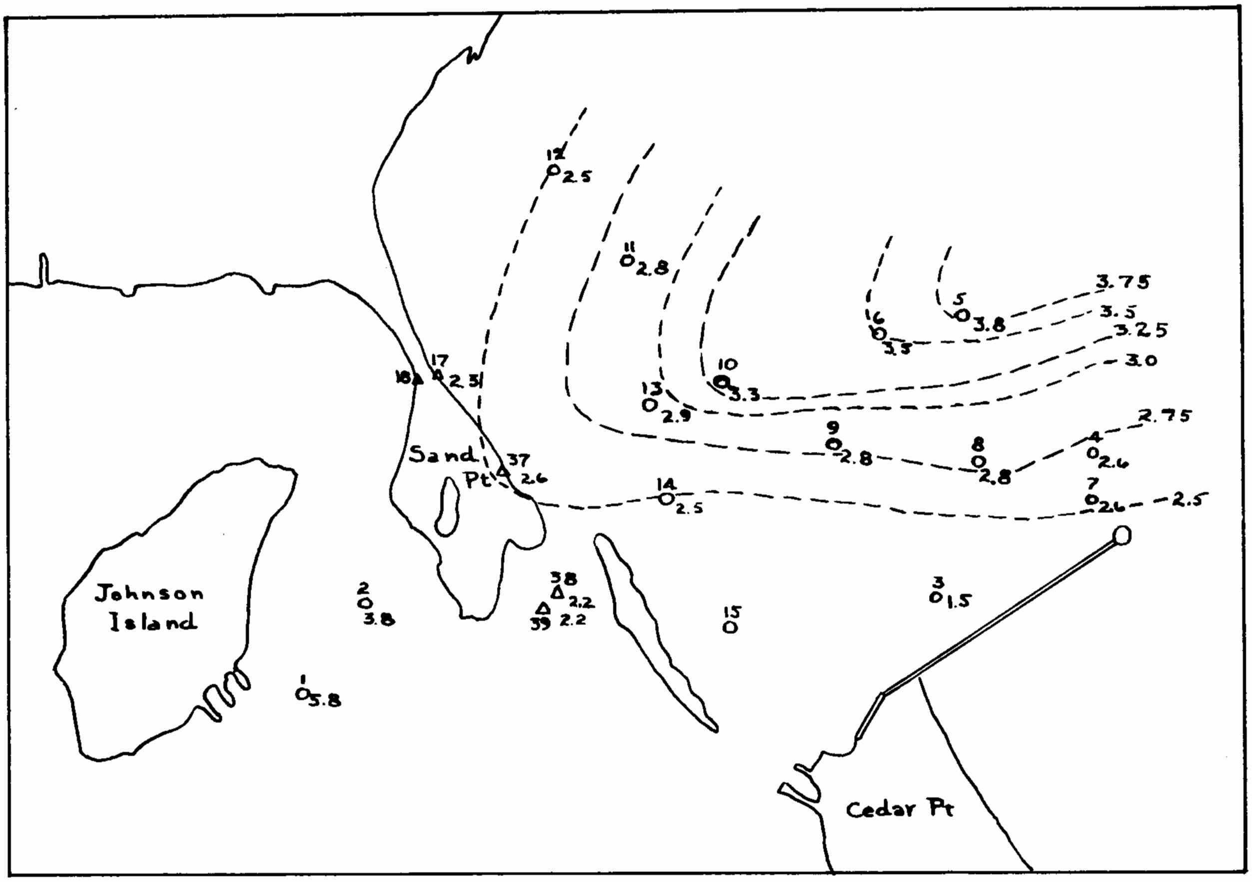


Figure 4

Phi Medians of Bottom Samples, Outer Sandusky Bay

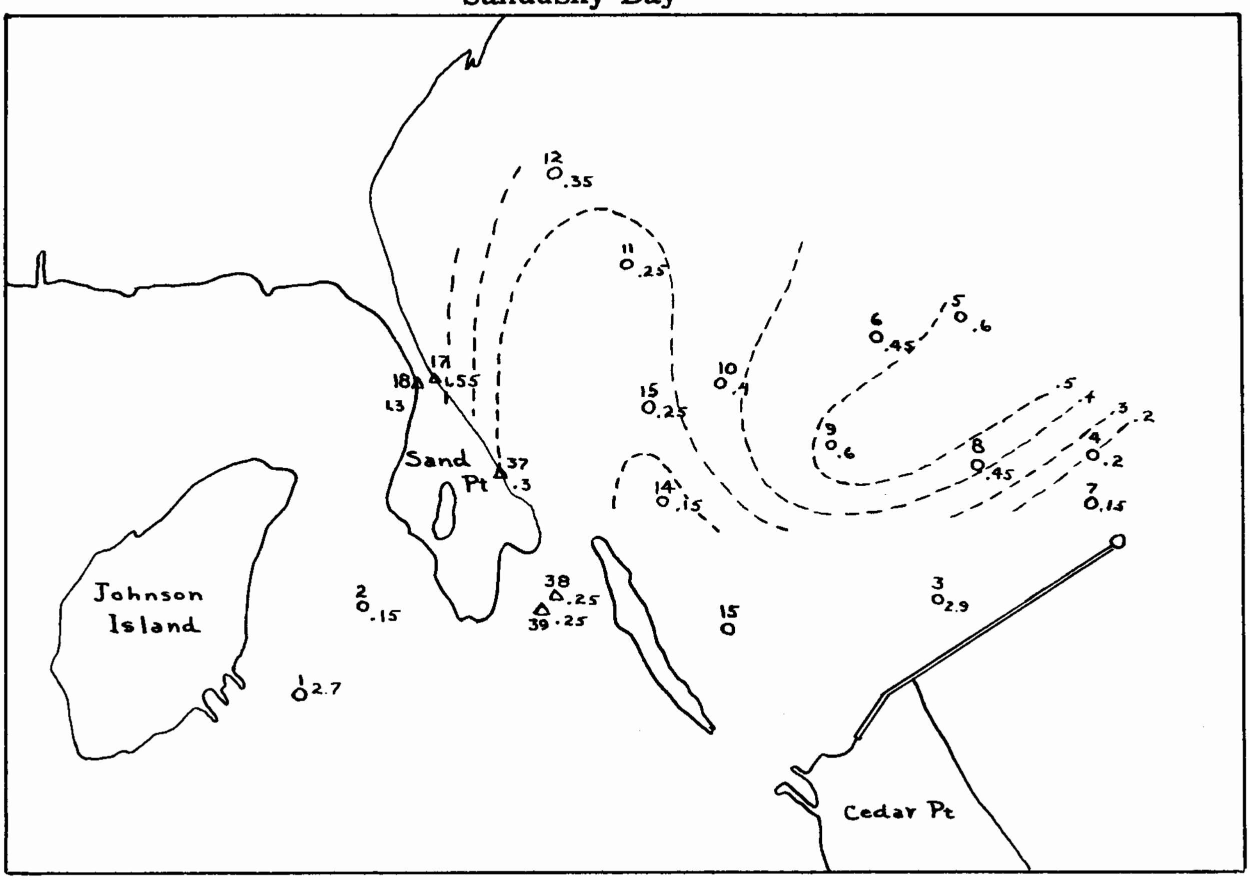


Figure 5

Phi Quartile Deviations of Bottom Samples, Outer Sandusky Bay

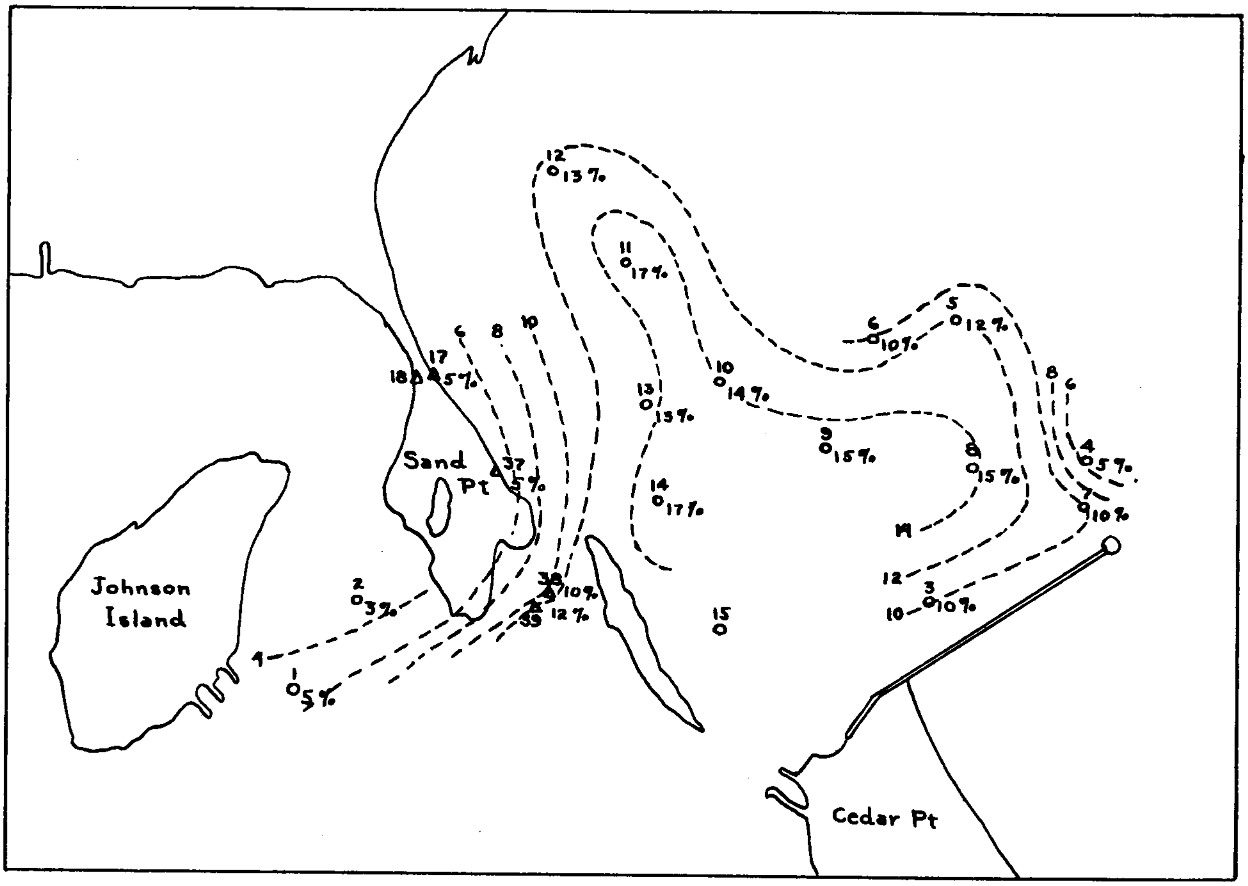


Figure 6

Total of Heavy Minerals in Bottom Samples, Outer Sandusky Bay

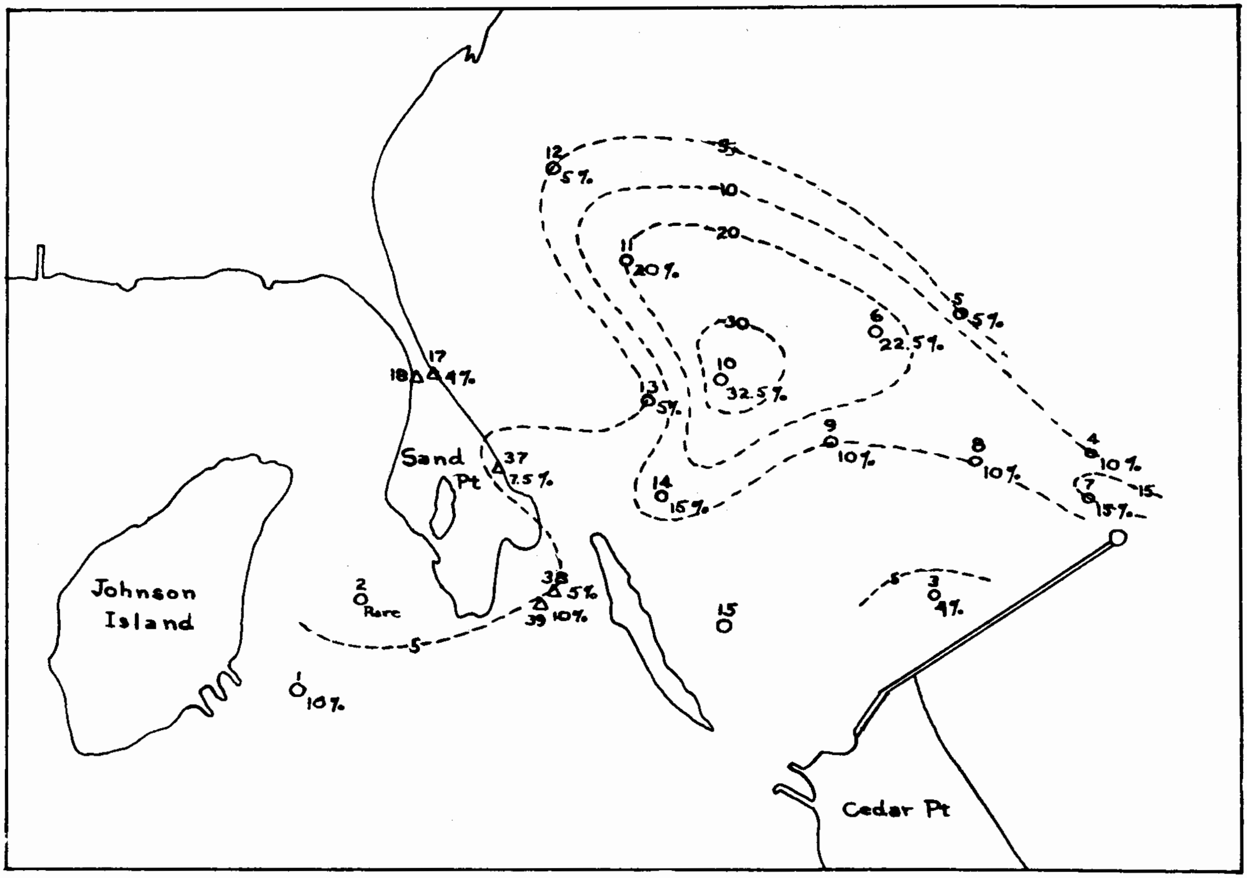


Figure 7
Magnetite-Ilmenite in Bottom Samples,
Outer Sandusky Bay

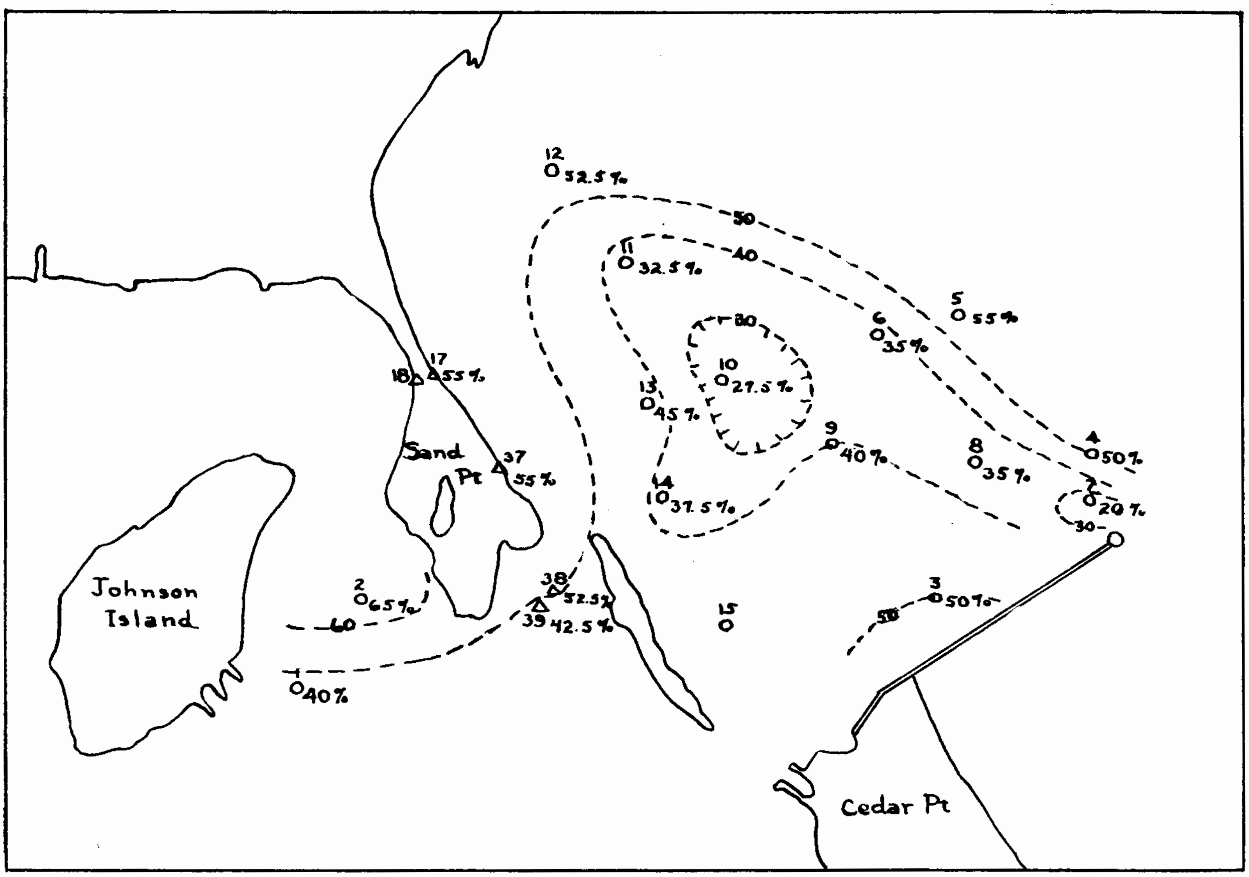


Figure 8
Amphibole (chtefly hornblende) in Bottom
Samples, Outer Sandusky Bay

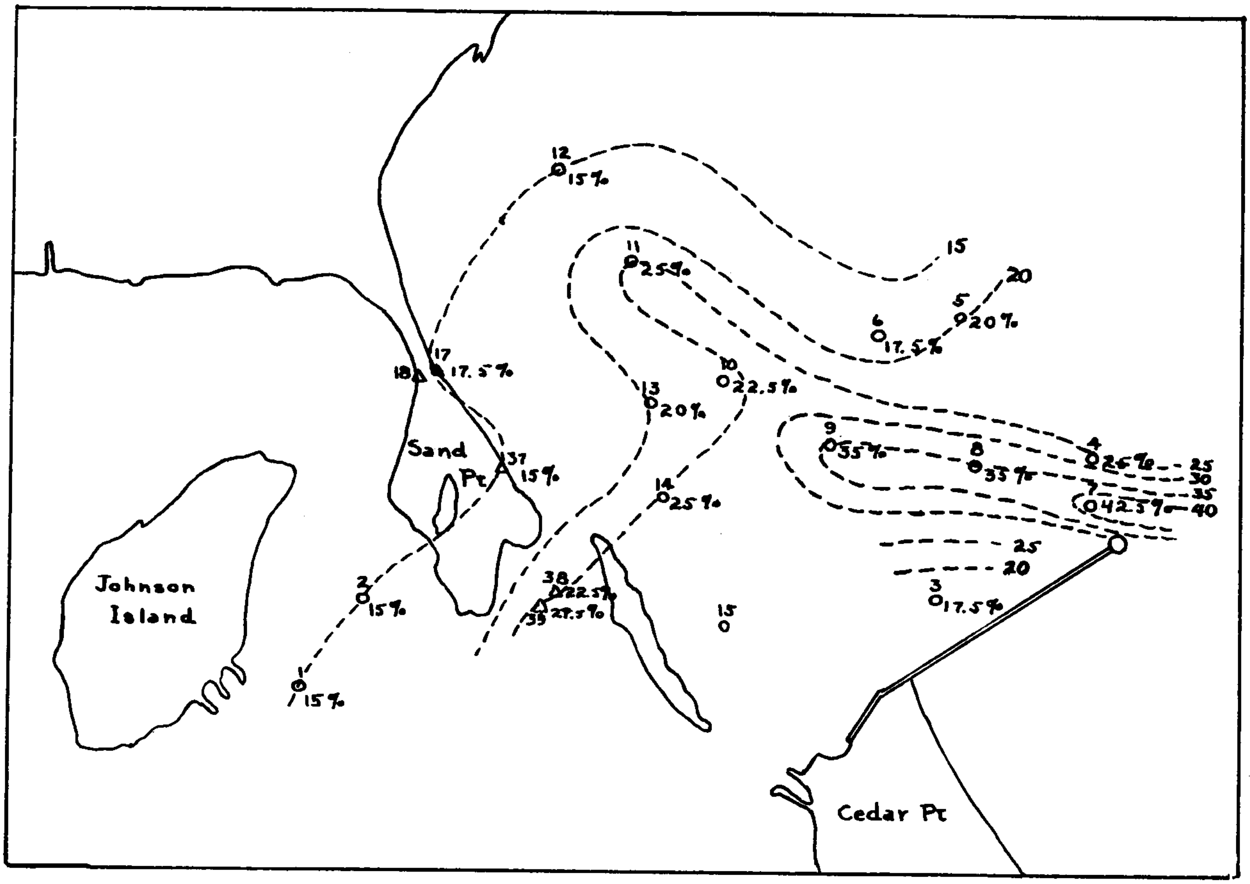


Figure 9
Garnet in Bottom Samples, Outer Sandusky Bay

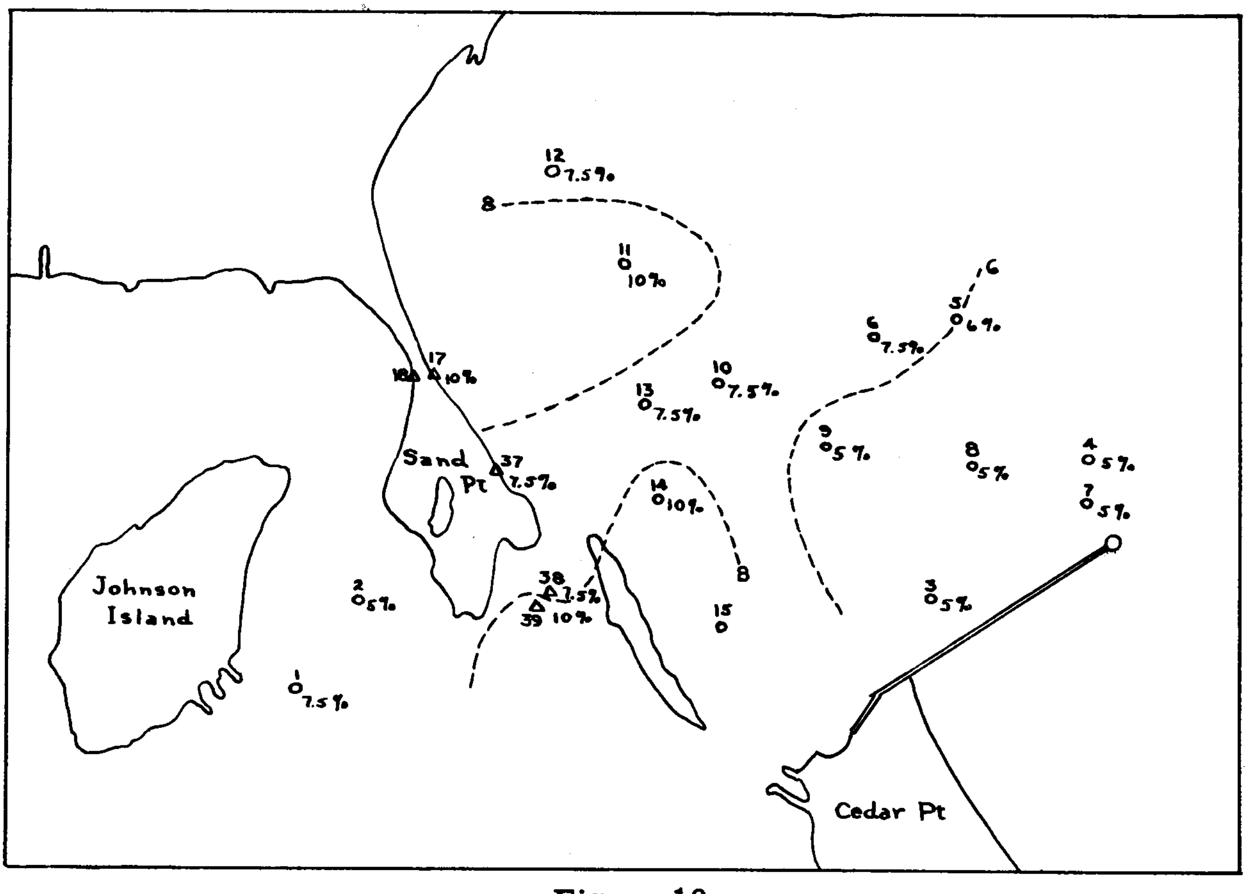


Figure 10
Zircon in Bottom Samples, Outer Sandusky Bay

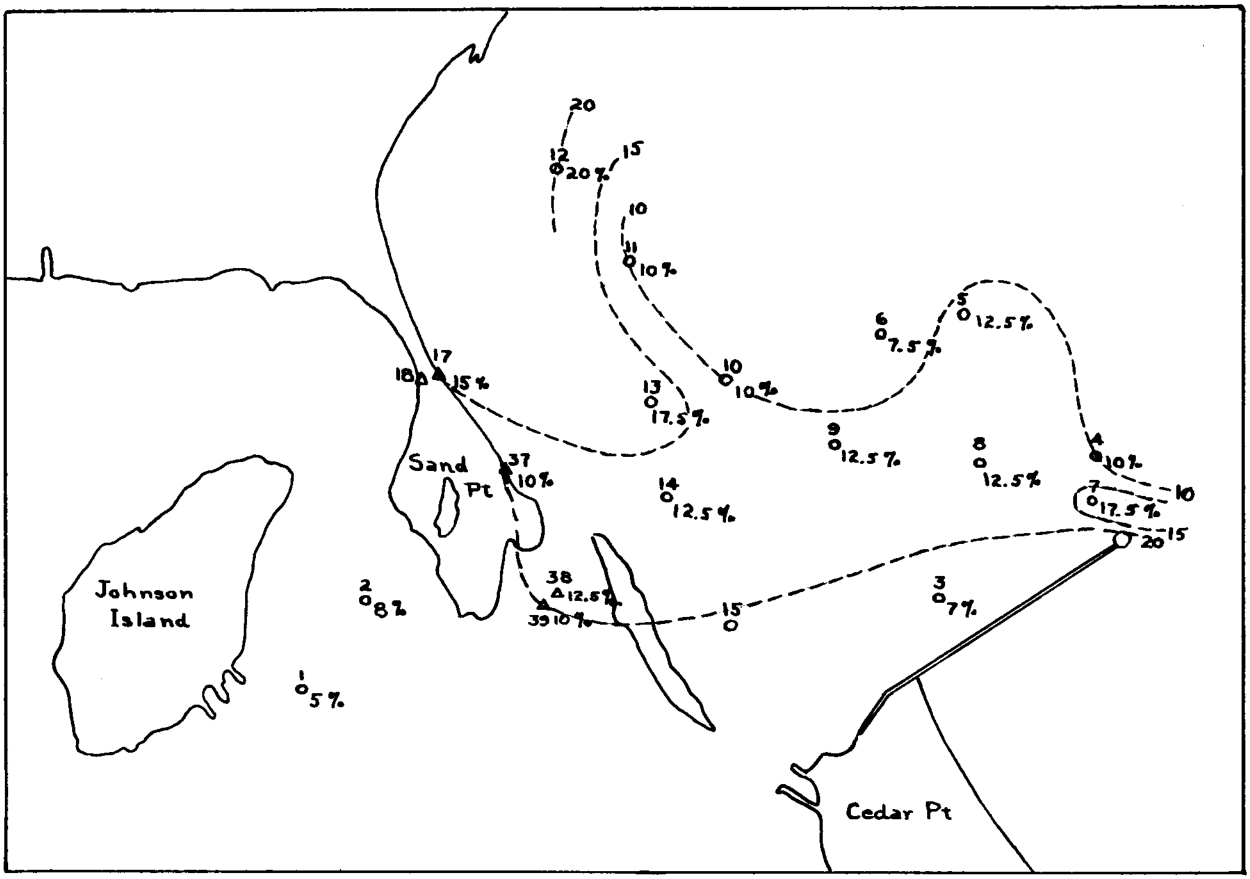


Figure 11
Hypersthene in Bottom Samples, Outer Sandusky Bay

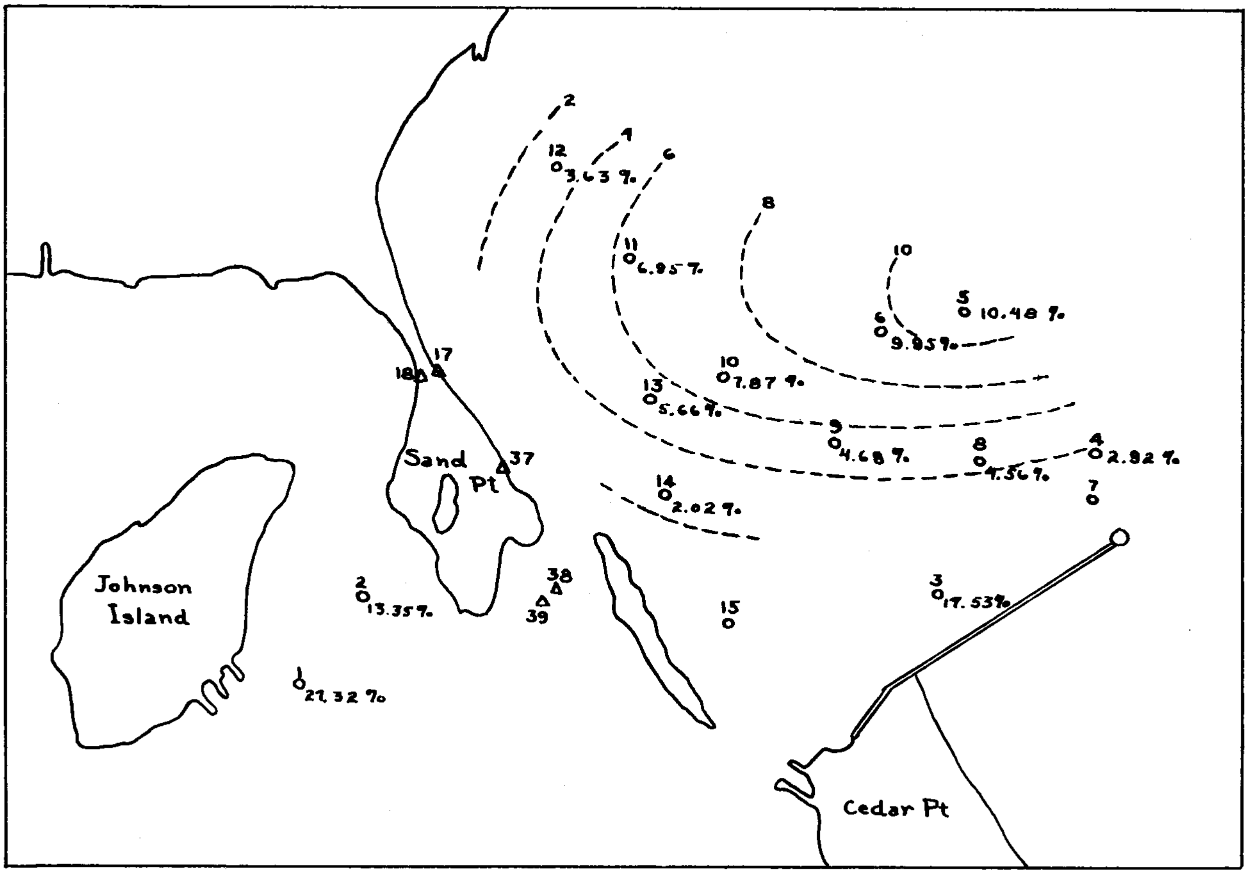
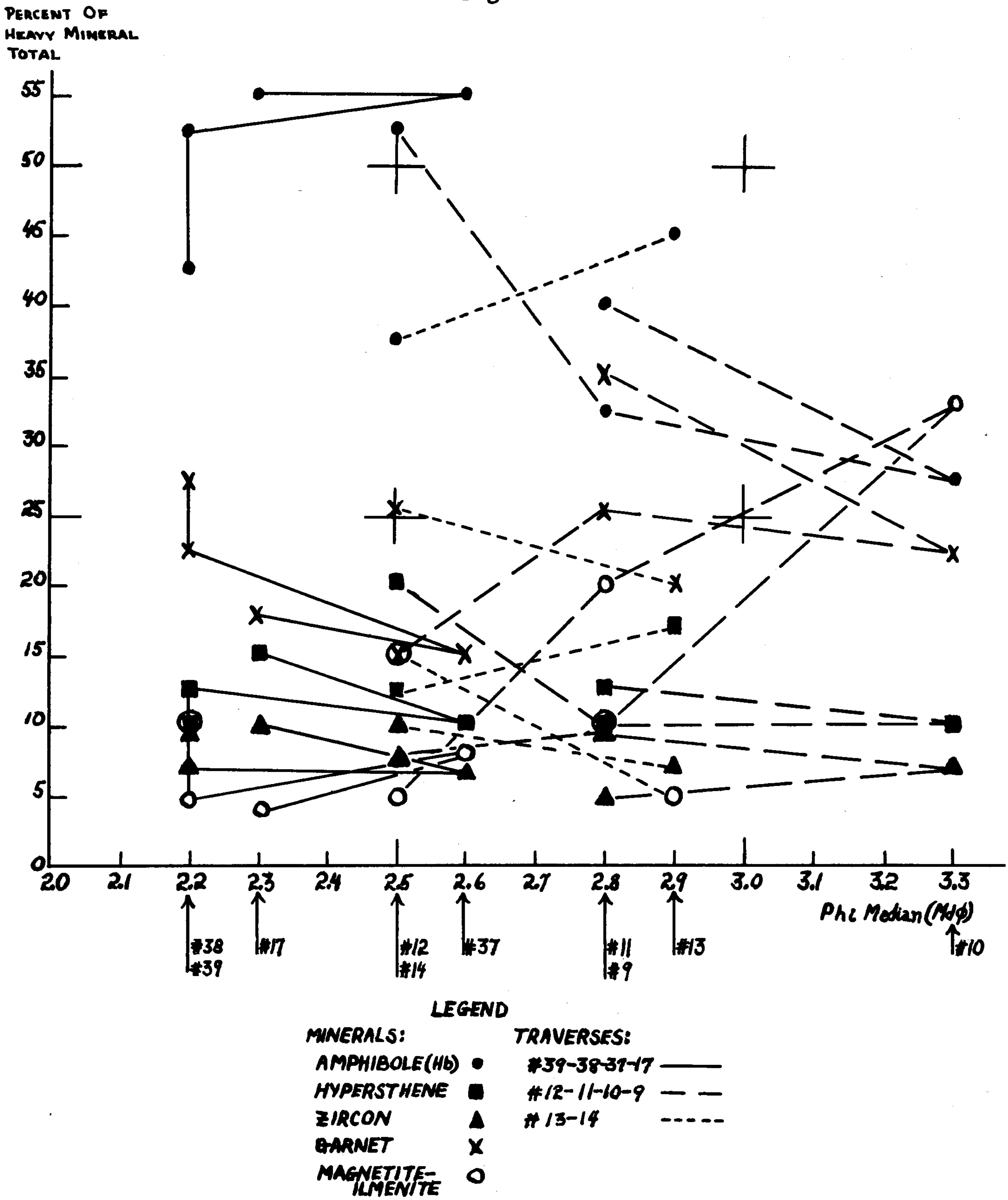


Figure 12
Carbonate in Bottom Samples, Outer Sandusky Bay

Figure 13



Heavy Mineral Composition vs. Phi Median Parallel to Outer Sandusky Bay Bottom Contours

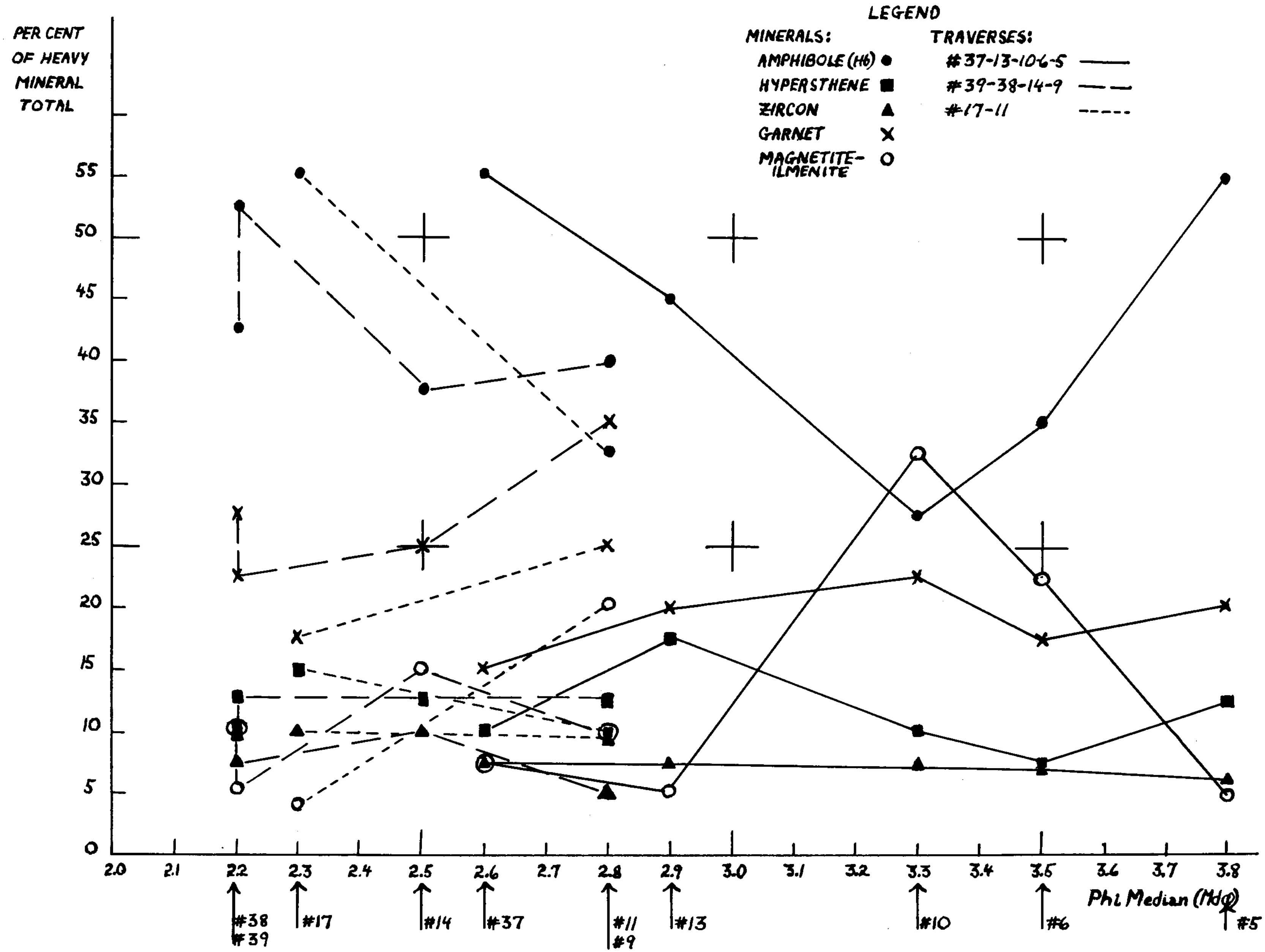


Figure 14

Heavy Mineral Composition vs. Phi Median Normal to Outer Sandusky Bay Bottom Contours

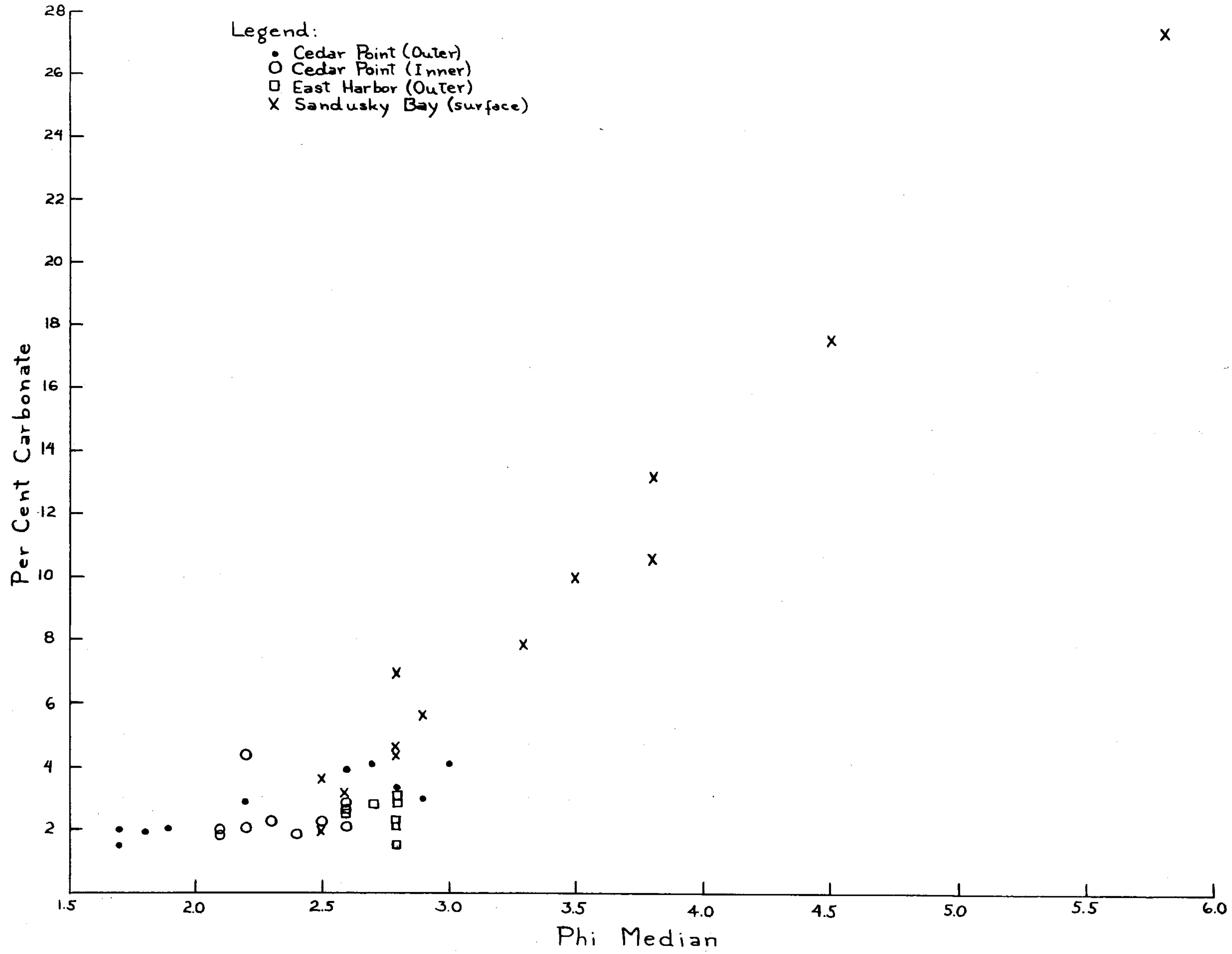


Figure 15
Per Cent Carbonate vs. Phi Median: Bottom Surface and Beach Samples

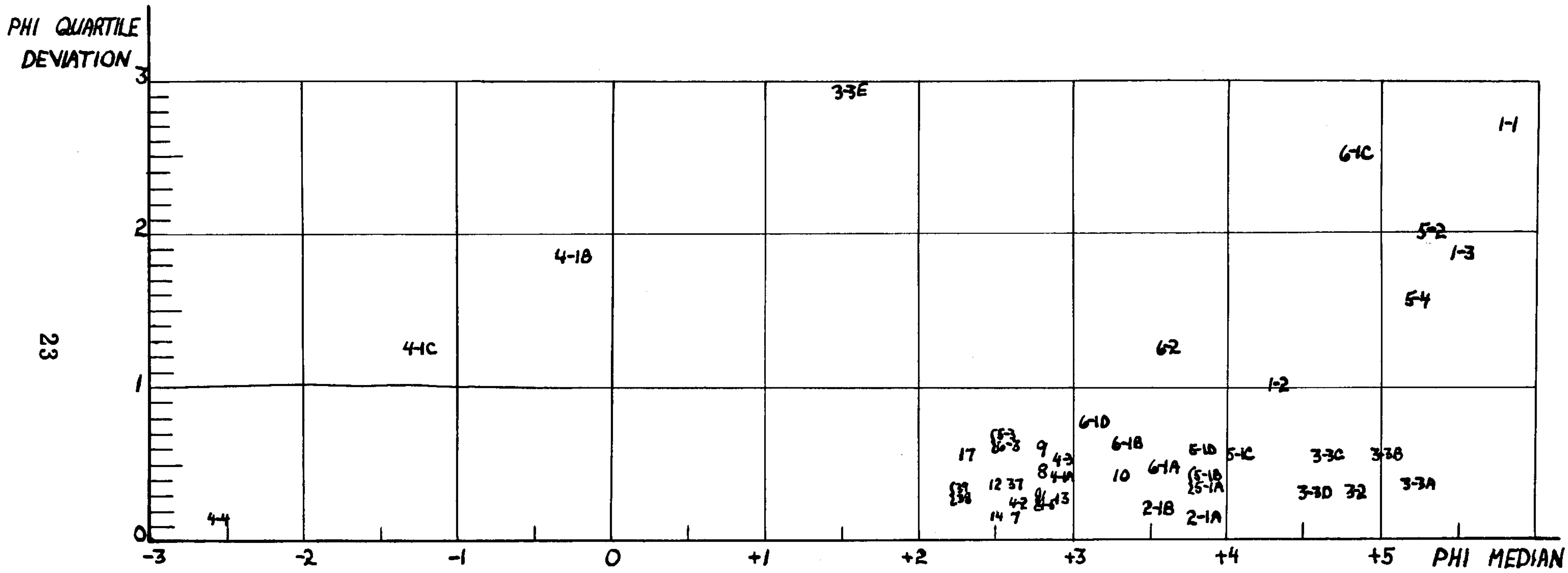


Figure 16

Phi Quartile Deviation vs. Phi Median: Surface and Subsurface Samples of Outer Sandusky Bay

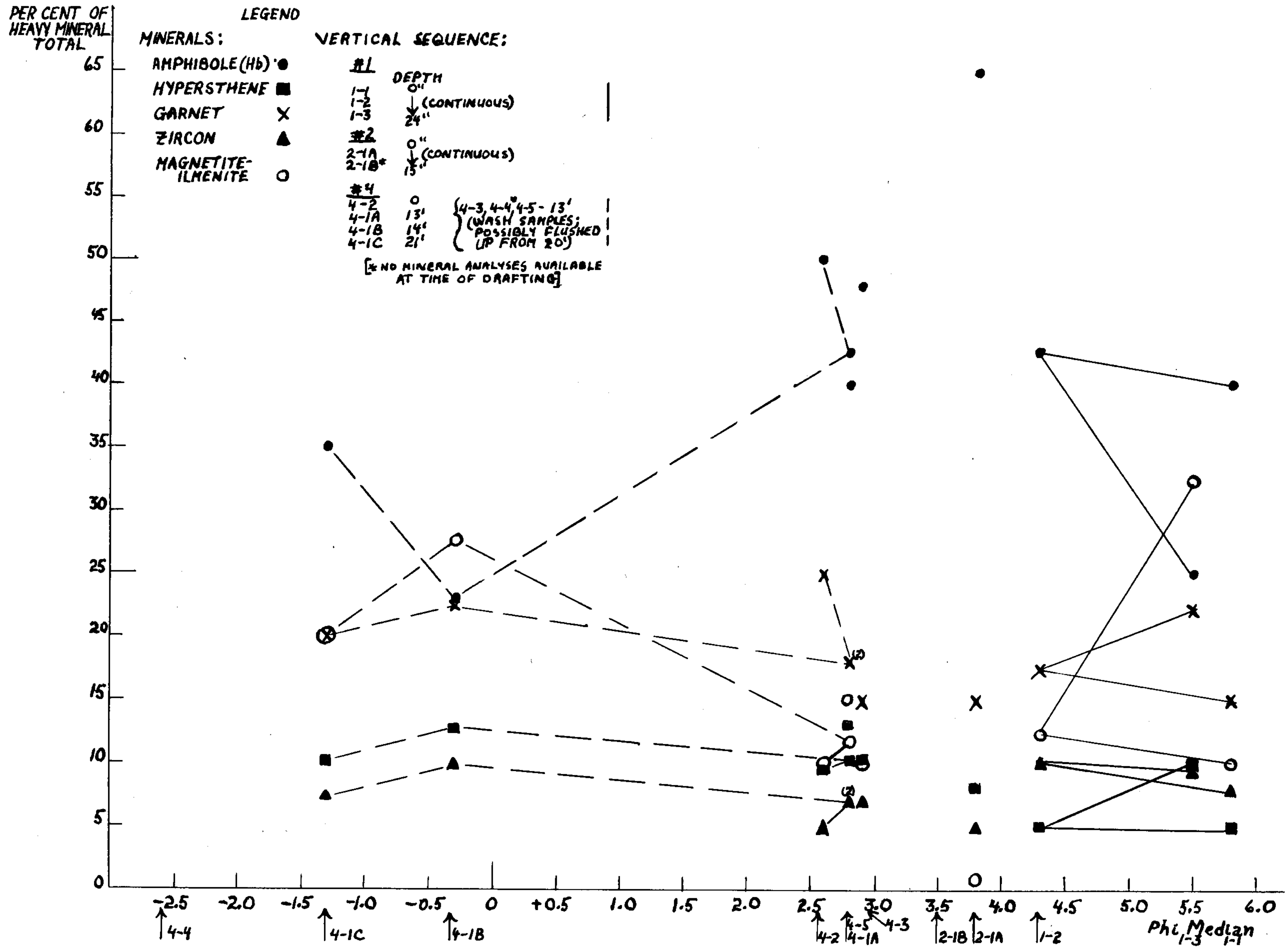


Figure 17

Heavy Mineral Composition vs. Phi Median: Vertical Sequence

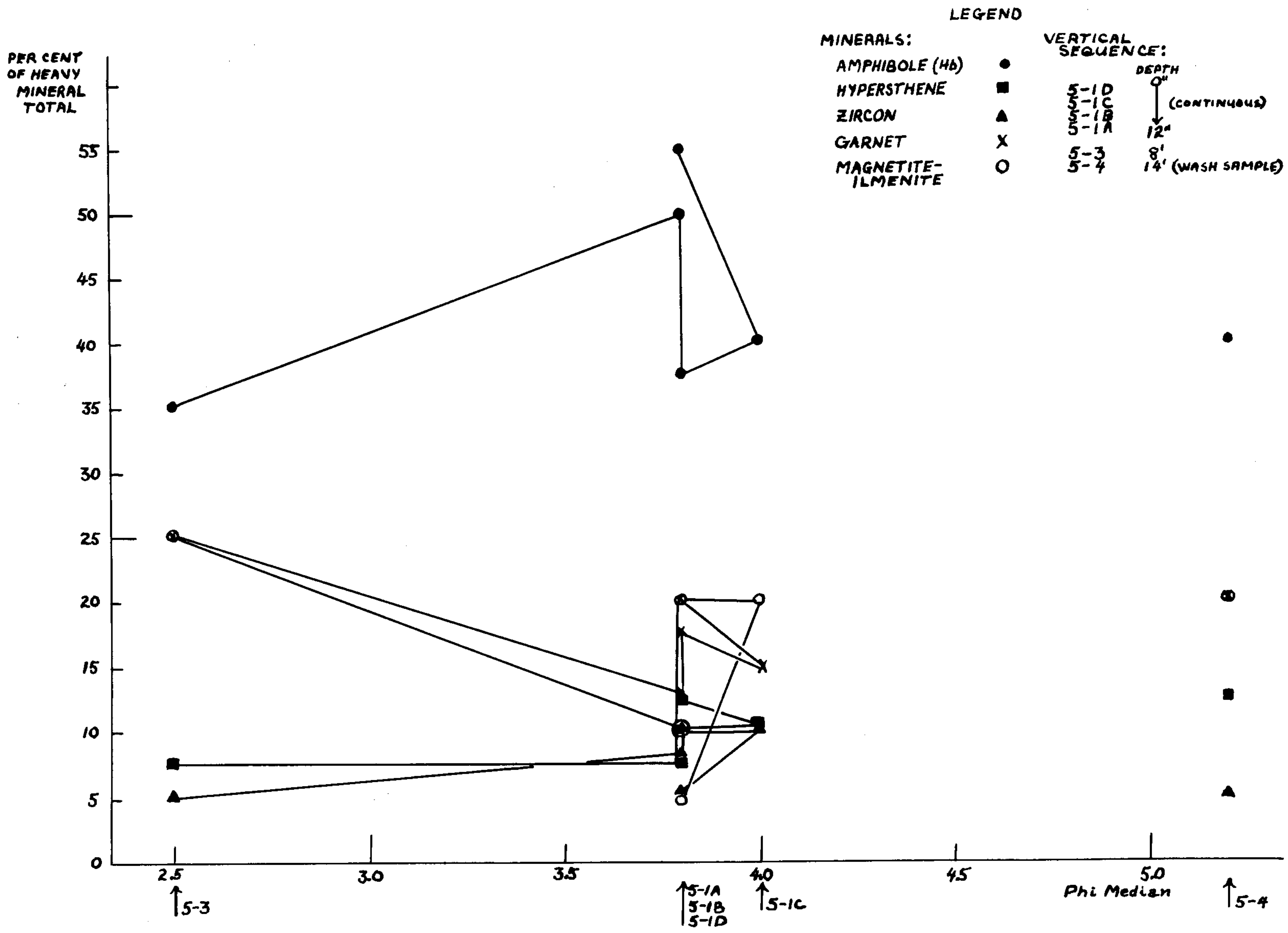


Figure 18

Heavy Mineral Composition vs. Phi Median: Vertical Sequence

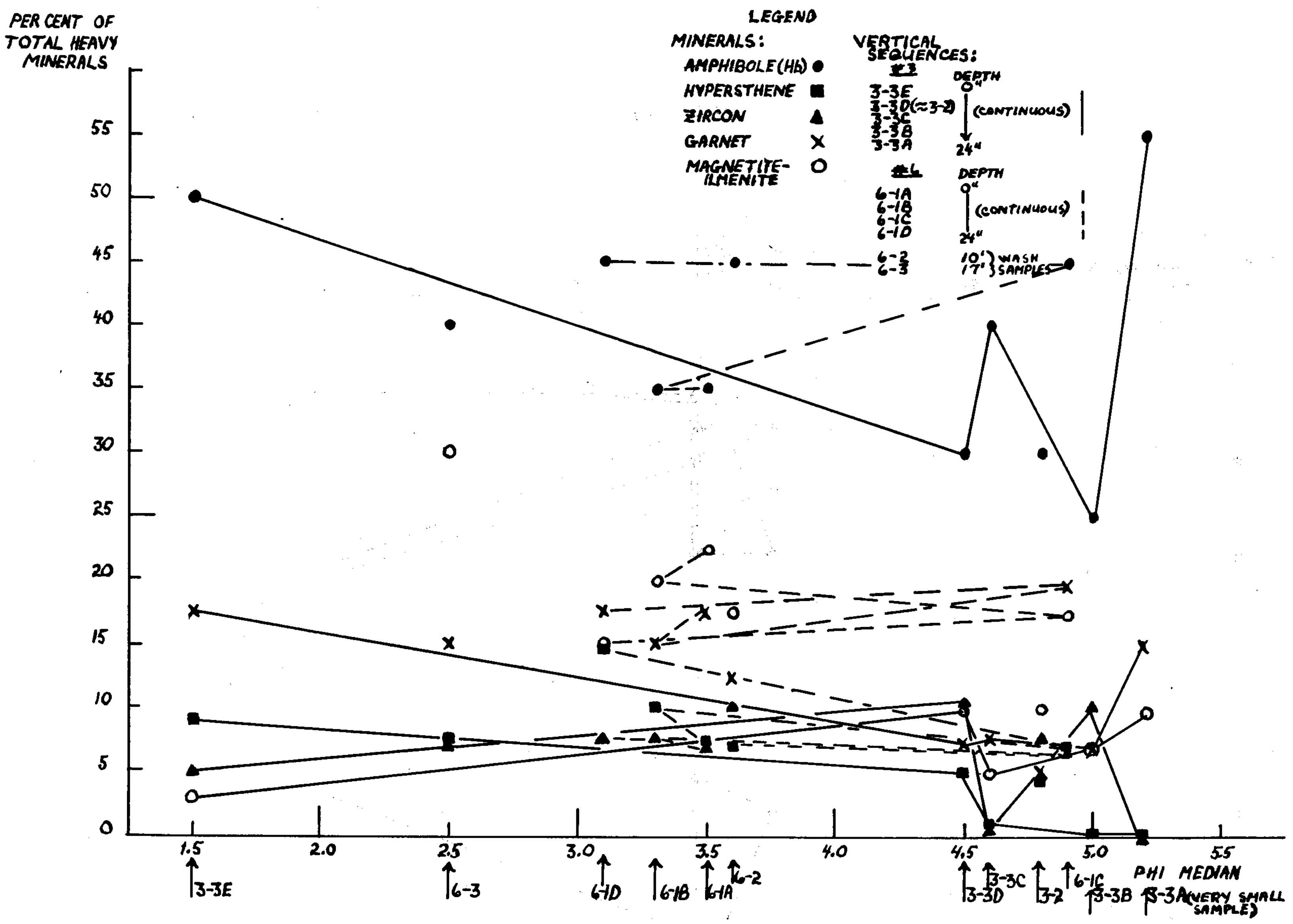


Figure 19

Heavy Mineral Composition vs. Phi Median: Vertical Sequence

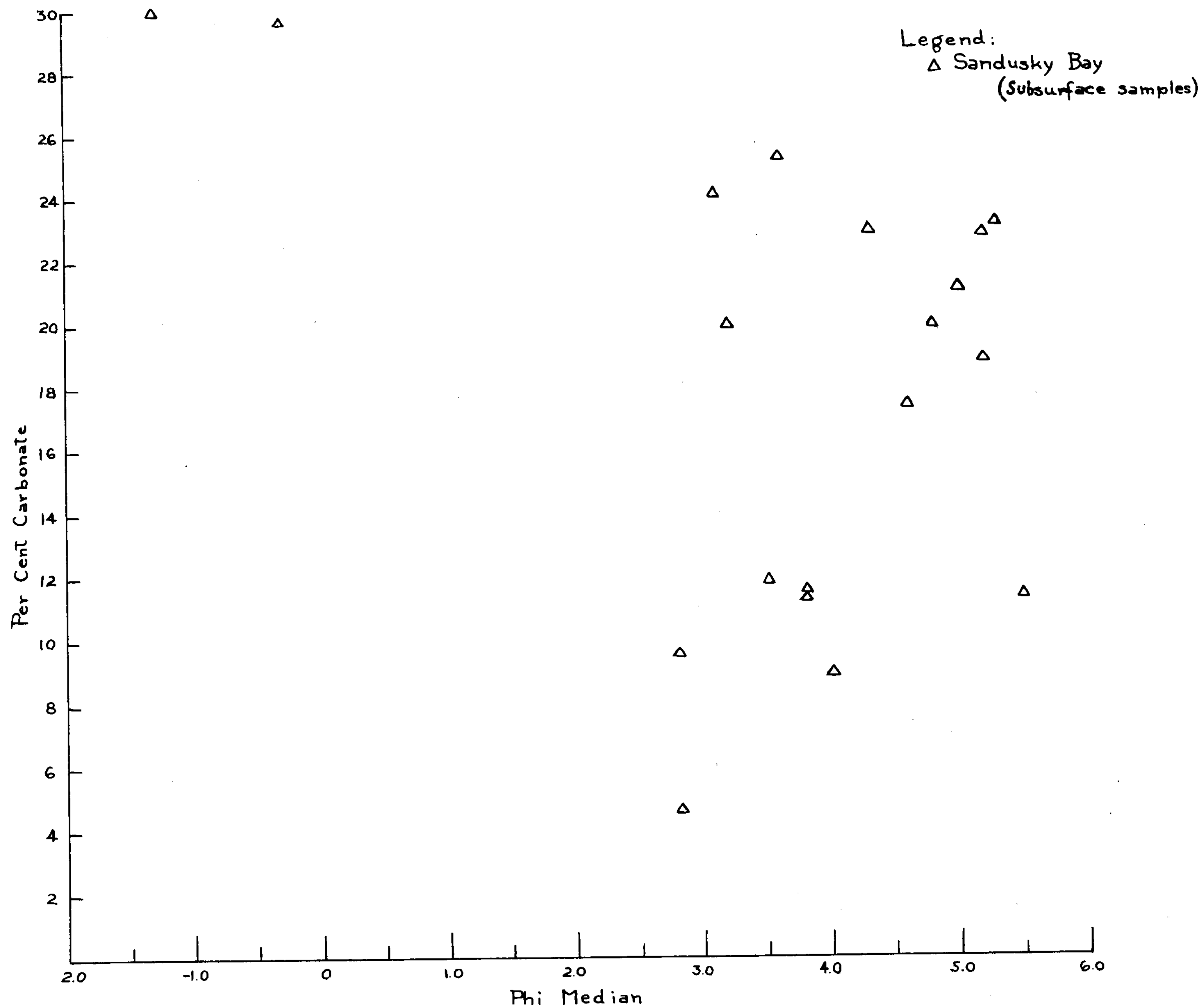


Figure 20

Per Cent Carbonate vs. Phi Median: Subsurface Samples of Outer Sandusky Bay

Cedar Point Beach

At Cedar Point, samples were collected along the water's edge (outer line) and along the beach ridge (inner line). The phi median ($Md\phi$) and phi quartile deviation ($QD\phi$) values are plotted in Fig. 21. The general trend of $Md\phi$ values for the series along the outer line agrees with the trend reported by Pettijohn and Ridge (1932), although the values at corresponding localities are not in strict agreement. The trend is that of finer grain size (larger phi values) toward the northwest; $QD\phi$ along the same line shows a decrease toward the northwest, indicating greater sorting in the supposed direction of transport.

Along the beach ridge, the grain size also decreases toward the northwest, but the rate of decrease is much less than that along the outer line. Along the inner line there does not appear to be a significant change in the values of $QD\phi$, indicating that sorting along this line has probably not taken place to any detectable degree. This is not surprising, in view of the fact that here the mixing or stirring action of wind on the sediments becomes quite important, and the variability in the direction of the wind, especially over an irregular surface, could well account for the characteristics observed in Fig. 21.

The results of heavy mineral analyses appear in Fig. 22. The following may be observed from the diagram:

(a) Total heavy mineral content decreases from southeast to northwest, both along the inner and outer lines of samples; the abundances along the inner line are somewhat more erratic than those collected along the outer line. Most of the decrease along each line takes place within the southeastern half.

(b) Amphibole increases erratically toward the northwest; the abundance of amphibole along the inner line fluctuates more than along the outer line. The largest breaks in slope are similar to those in the corresponding curves for total heavy minerals.

(c) Along both lines, magnetite-ilmenite (where reported) and garnet bear a reciprocal relationship to the amphibole.

(d) The abundance curves for zircon and hypersthene are very similar for the outer line of samples, and are roughly similar for the inner line. Along both outer and inner lines, from the center of the area studied to the southeastern limit, the curves are similar to the amphibole curves.

Some of the variations reported are not in agreement with those described by Pettijohn and Ridge (1933). However, it must be remembered that the stations reported in this study are more closely spaced than those of Pettijohn and Ridge; also, later observations, to be reported in a subsequent paper, indicate that there are large concentrations of some of the heavy minerals along the beach, so that a single sample in one area might very well show much higher concentrations than that in the "average" beach material for quite a large area around the sample.

With regard to variations in carbonate content (Fig. 23), the outer line shows a significant increase in carbonate toward the northeast, while the inner (beach ridge) line shows one high concentration but no detectable overall trend. In Fig. 15, the outer line samples show a slight increase in carbonate as Mdϕ increases; this trend appears to intersect or, possibly, to join the trend of the Sandusky Bay surface samples. The inner line samples show remarkable uniformity in the abundance of carbonate, regardless of changes in Mdϕ. The carbonate content of the Cedar Point samples is significantly lower than that in most of the Sandusky Bay samples.

East Harbor Beach

At the East Harbor Beach, samples were collected along the water's edge, on the beach ridge in one locality (#29), and along a swampy area to the rear of the beach. The "inner line," so-called, is not really a line, but an inshore zone.

Values of the phi median (Mdϕ) along the outer line are remarkably uniform (Fig. 24), in contrast to the systematic variation observed along Cedar Point (Fig. 21). Values of the phi quartile deviation (QDϕ) show no overall systematic change along the beach: a trend line drawn through these points would be approximately horizontal.

Since mechanical analyses have been run for only a few of the samples from the inner zone, no figures on mechanical analyses for this group are presented.

With regard to variations in heavy minerals (Fig. 25), the total heavy mineral content is fairly constant along the length of the beach, the values increasing toward the southeastern end. In the inner zone, the abundance of heavy minerals is similar to that along the outer line.

None of the individual heavy minerals shows significant systematic changes along the outer line; amphibole and garnet occur in reciprocal proportions. The abundance curve of hypersthene is roughly similar to that of amphibole. Magnetite-ilmenite occurs in such small quantities in the samples studies that the observed variations in abundance could not be resolved into meaningful fluctuations, at least with the techniques used in this study.

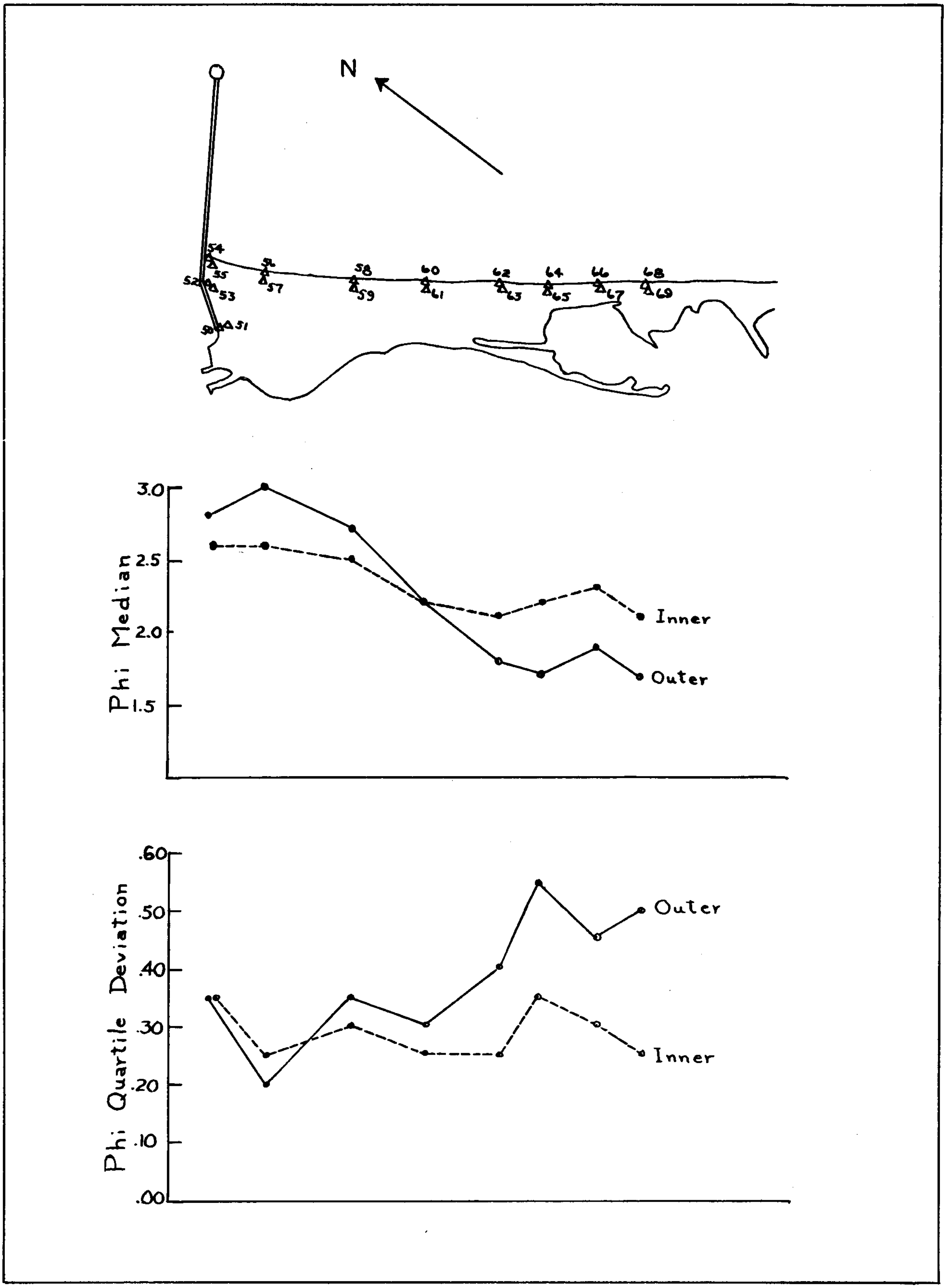


Figure 21

Phi Medians and Phi Quartile Deviations: Cedar Point Beach

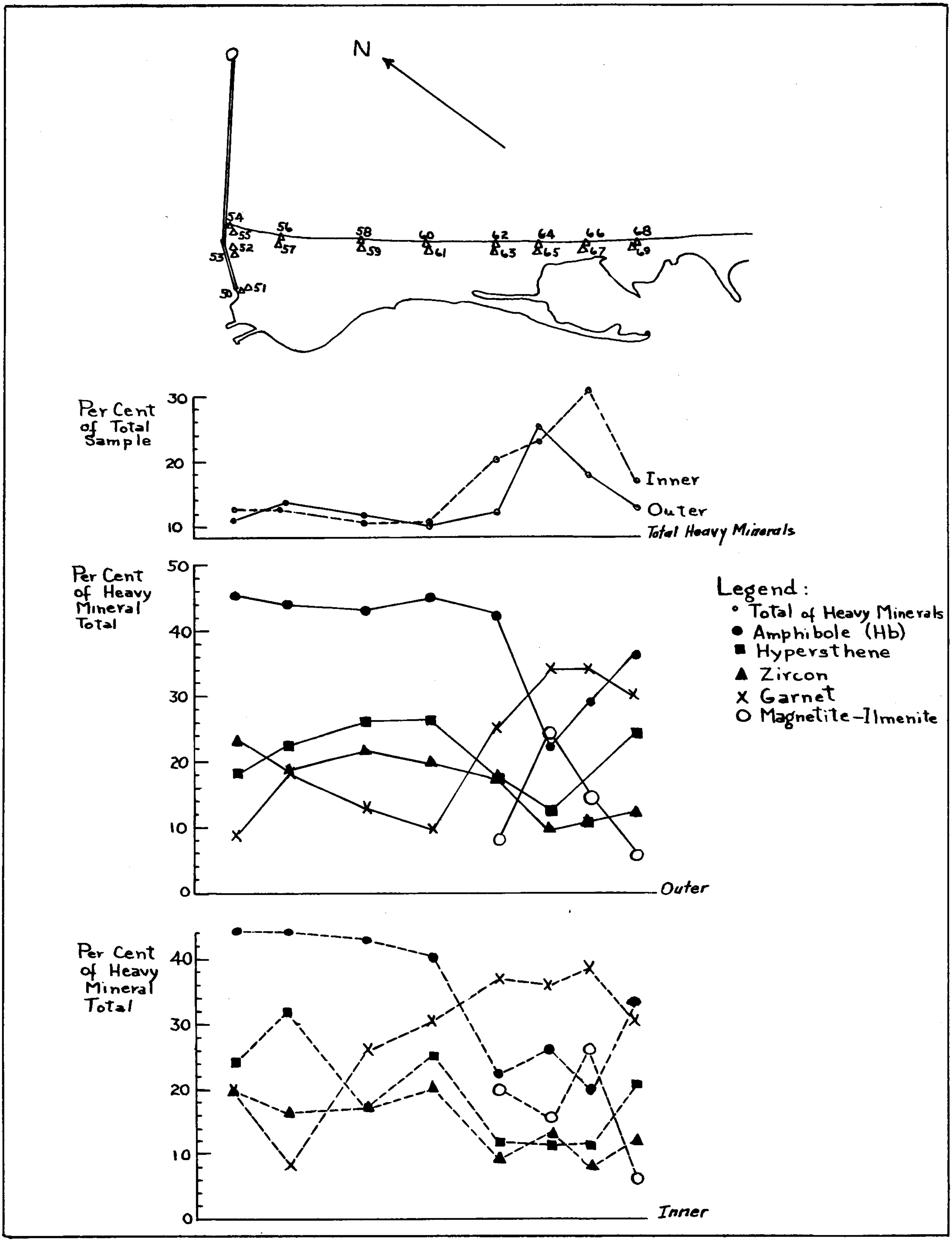


Figure 22

Heavy Mineral Composition: Cedar Point Beach

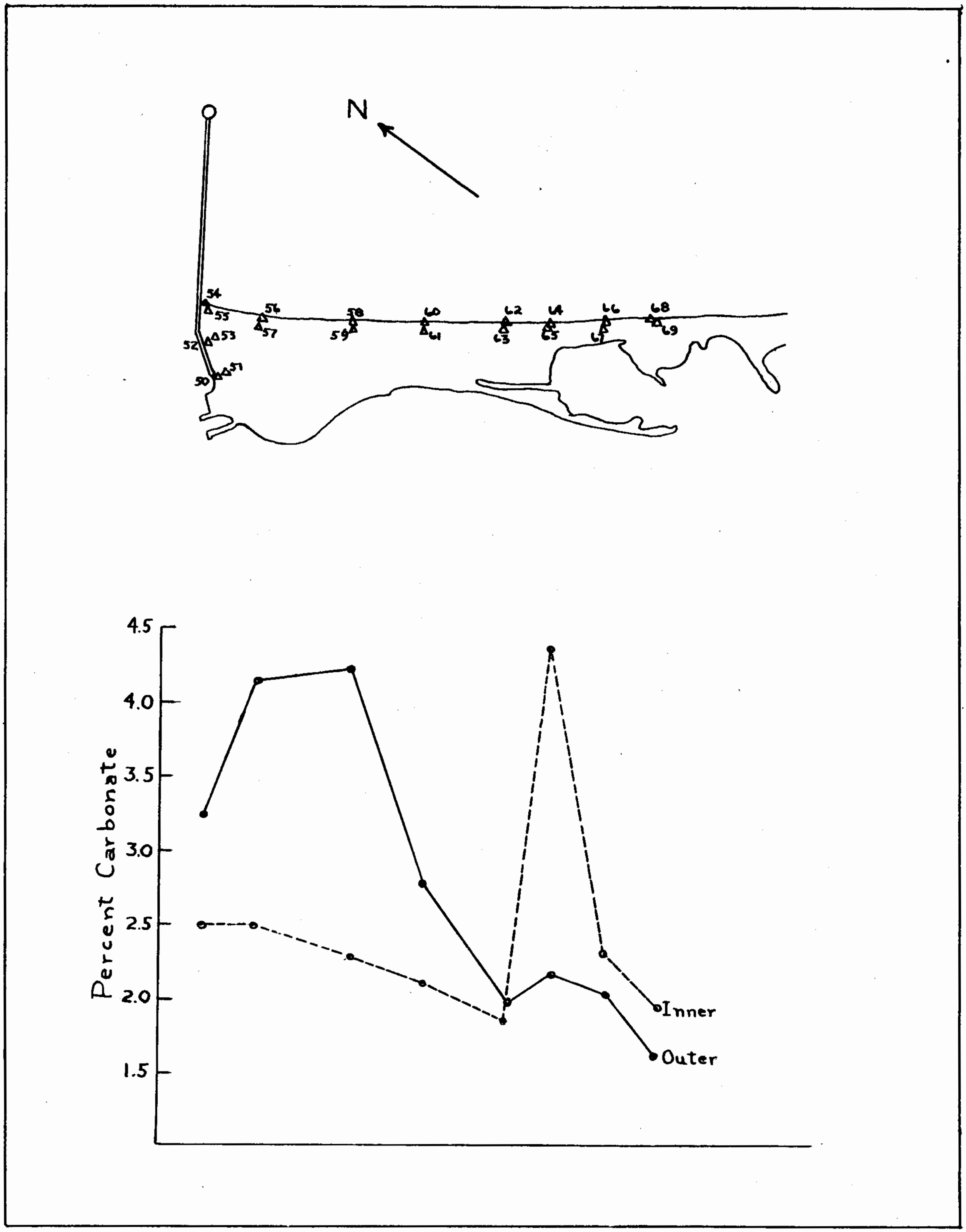


Figure 23

Per Cent Carbonate: Cedar Point Beach

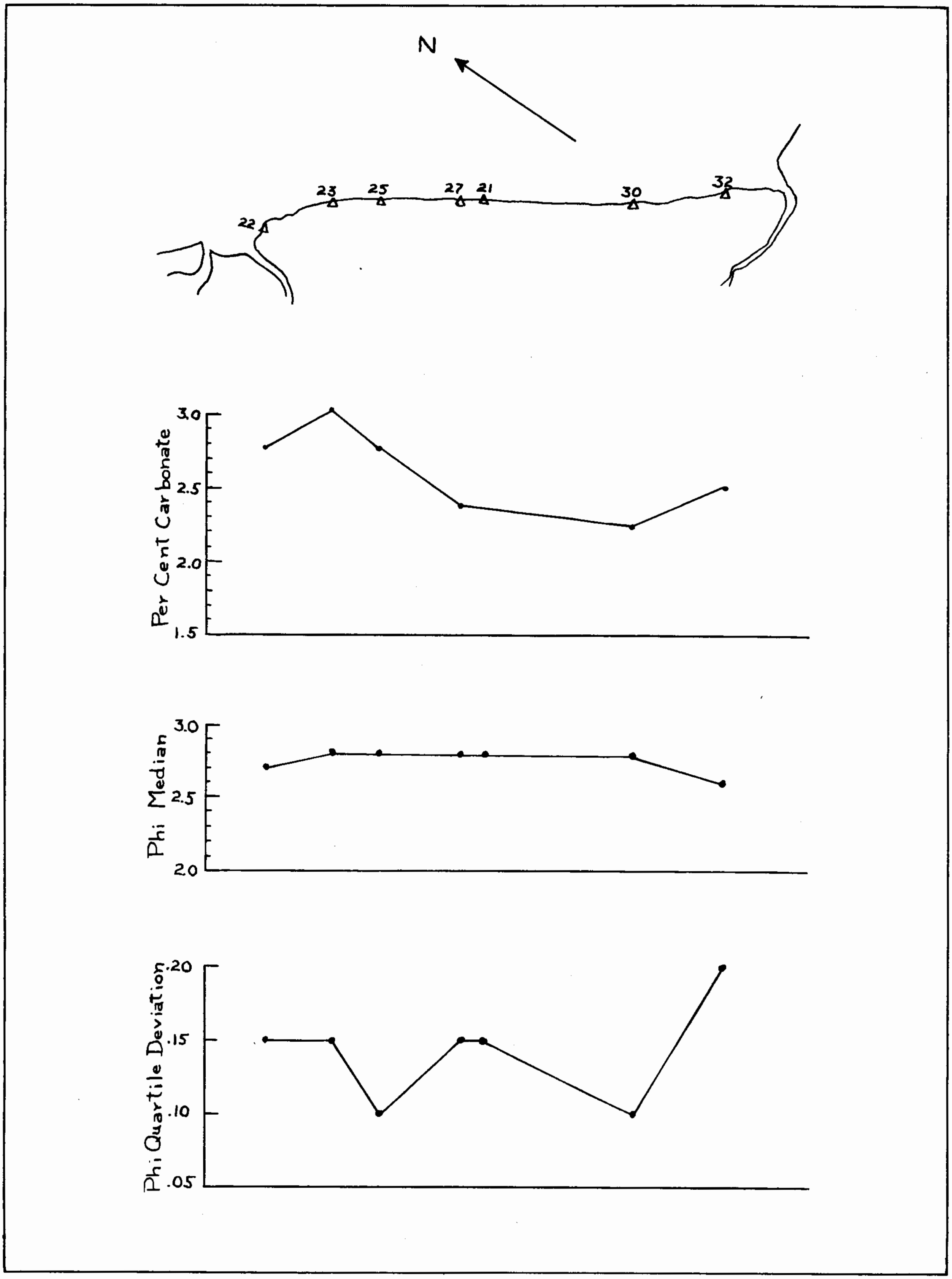


Figure 24

Phi Median, Phi Quartile Deviation, and Per Cent Carbonate: East Harbor Beach

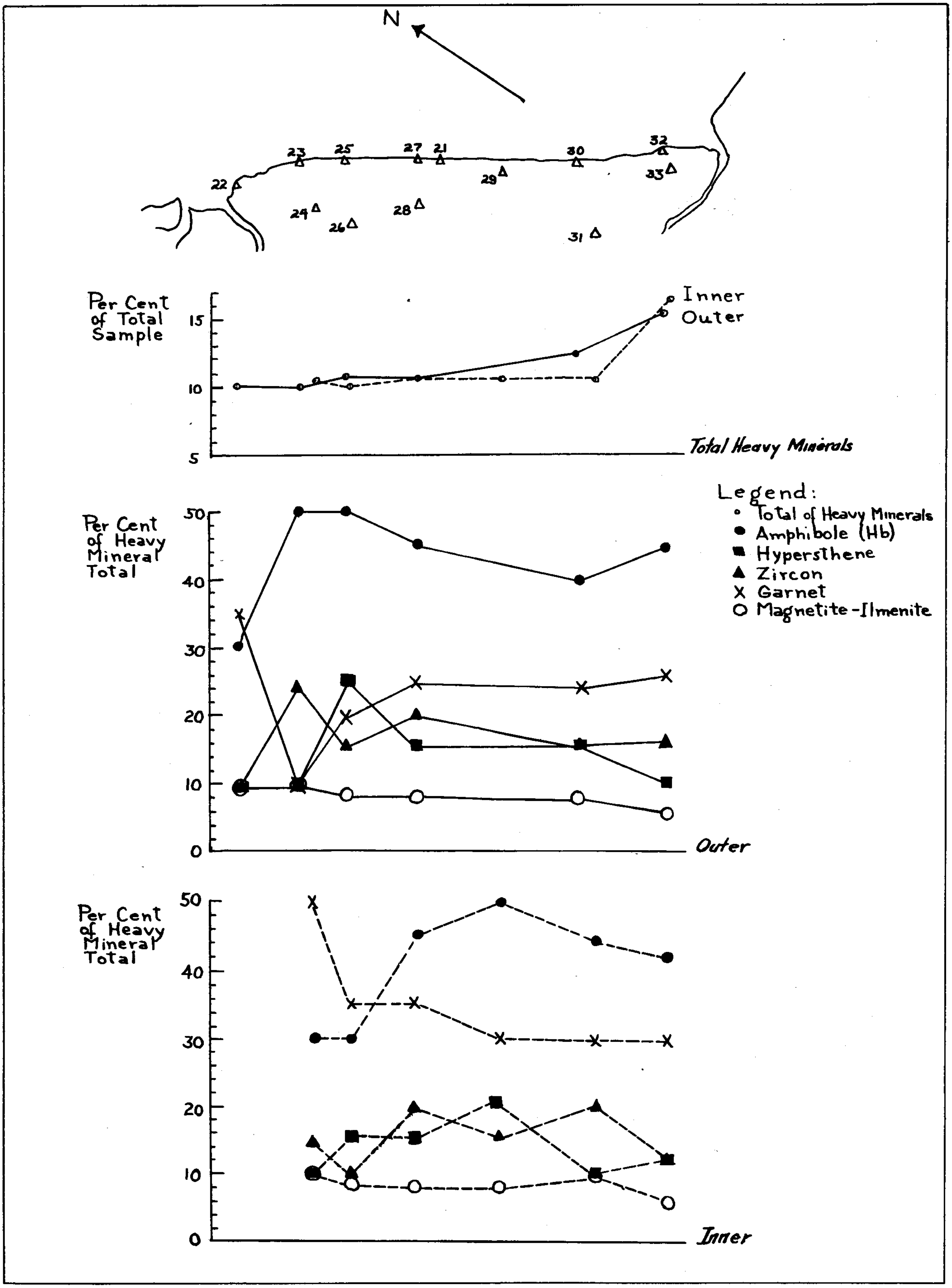


Figure 25

Heavy Mineral Composition: East Harbor Beach

In the inner zone, garnet and amphibole show a reciprocal relationship. Again, hypersthene and amphibole have similar abundance curves. Hypersthene and zircon occur in reciprocal proportions, but the smallness of the percentages on which these curves are drawn casts doubt on the accuracy of a comparison of the curves.

In this area, as at Cedar Point, more recent field observations have revealed patchy concentrations of heavy minerals. Variation series should be so designed that such patches are excluded from series of "average" materials, or samples collected from such patches should be tagged in some way to prevent their inclusion in the series as an equivalent member. Studies now in progress in this area should provide a more complete picture of the occurrence and concentration of minerals in the beach sediments.

The carbonate content along the outer line of samples at East Harbor is erratic (Fig. 24). The quantities involved, however, are so small, that tiny variations appear large when plotted as in Fig. 24. In Fig. 15, the East Harbor samples show no relation between carbonate content and Mdϕ. The carbonate content is of the same order of magnitude as at Cedar Point. Data are not available for carbonate content along the inner zone.

CONCLUDING REMARKS

It is obvious from the foregoing presentation of data that much more field and analytical work are necessary to understand the sedimentary processes in Lake Erie in the vicinity of Sandusky. As more data are assembled, it will become possible to make extensive comparisons with results obtained by other workers (Pettijohn, 1931; Pettijohn and Ridge, 1932, 1933).

More complete vertical sections are required; this will be accomplished, it is hoped, with a coring rig modified for use in Lake Erie. Periodic topographic surveys of offshore and shoreline areas are necessary to define the changes in the surface of shifting masses of sediment. Laboratory techniques will be refined to describe with great accuracy the mineralogical and physical characteristics of the sediments; attributes of selected grades must be investigated.

In conclusion, the most striking relations observed in this study, at least in the authors' opinion, are as follows:

(a) The reciprocal relation between the abundance of amphibole (chiefly hornblende) and magnetite-ilmenite; this relation holds in all three of the areas studied. Also variations in the abundance of garnet are often very similar to those of magnetite-ilmenite.

(b) The increase in carbonate content with decrease in grain size (i.e., with increase in phi median) in the Sandusky Bay surface sediments. The values for carbonate content of the Cedar Point and East Harbor samples form a consistent trend with that of the Sandusky Bay surface sediments, but taken alone, their trend, if it exists, is not clearcut. The values for carbonate content of the subsurface sediments of Sandusky Bay do not conform to the trend of the surface sediments.

These and other relations presented in earlier parts of this report will be reviewed in later papers, as additional data become available.

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